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MONTEREY, CALIFORNIA

THESIS

MESH NETWORKS WITHIN A DISTRIBUTED OPERATIONS FRAMEWORK UTILIZING IP BASED RADIOS

by

Randall J Simmons
Christopher C Curran

September 2007

Thesis Advisor: Alex Bordetsky
Co-Advisor: Carl Oros

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Currently the USMC employs numerous radio sets to establish a tactical network in order to communicate in the Area of Operations. These radio sets include AN/PRC-150(C) HF, SINCGARS VHF, & AN/ARC-210 UHF radios. In every instance, these sets require individualized training and calibration to ensure that they all operate when needed. Further, these independent systems often have difficulty cross-communicating, as a result of incorrect time hacks, outdated fills, or improper frequency ID's, the list goes on. The way the Marine Corps has dealt with this is to establish a Tactical Network such as the Fire Support Coordination Center (FSCC) and Direct Air Support Center (DASC) that act as liaison between these elements. This slows down the passing of information and even loses words, phrases, and (often times) the meaning of what is being communicated. Emerging on the scene is the Global Information Grid (GIG) that brings with it a veritable cornucopia of information and a network of resources that would be unreachable by UHF/VHF/HF communications. To access this, the Department of Defense in general, and the Marine Corps in specific needs to adopt communications devices that speak the same language; IP-based radios are the only viable option.

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MESH NETWORKS WITHIN A TACTICAL FRAMEWORK UTILIZING IP BASED RADIOS

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

Currently the Armed Forces of the United States employ numerous radio sets to establish the tactical networks that are required to communicate across the vast territories that make up a battlefield environment. These radio sets include (but are not limited to) AN/PRC-150(C) HF, SINCGARS VHF, & AN/ARC-210 UHF radios. In every instance, these sets require individualized training, repair, calibration, and testing to ensure that they all operate properly when utilized. Compounding the problem is the fact that these independent systems often have difficulty cross-communicating, as a result of diverse issues such as incorrect time hacks, outdated fills, or improper frequency ID's. The list of problems goes on and on. The way the Marine Corps has dealt with this is to establish a tactical network that acts as liaison between various elements. However, these networks slow down the passing of information and even contribute to the loss of words, phrases, and (often times) the entire meaning of what is being communicated.

The recent emergence of the Global Information Grid (GIG) brings a veritable cornucopia of information and a network of resources that would be normally unreachable through legacy UHF/VHF/HF communications equipment. To access data, the Department of Defense in general, and the Marine Corps specifically, needs to adopt communications devices which can speak an identical language. IP-based radios are the only viable option that can serve as the

vehicle that ties the modern Marine Corps to Network-Centric Warfare and its expeditionary connectivity to the GIG.

Today, modern technology exists which can allow each of these disparate elements to communicate. A few off-the-shelf (OTS) systems have been fielded which allow units to communicate across great distances as well as in urban terrains. Additionally, these IP-based radio sets allow tremendous amounts of data to be passed and are not restricted to simply transmitting voice communications. Besides voice, these IP-based radios can also transmit data through various software packages. These include video, GPS data, time/date stamping, and many other pieces of information that increase the situational awareness of all players, from the infantryman to the Corps Commander.

With the increasing need for greater information at all levels, the time has come for the Marine Corps (and the DOD in a larger sense) to break from obsolete forms of communications and embrace technologies that will reduce the fog of war, reduce the potential for blue-on-blue engagements, and increase the situational awareness of the warfighter on the tactical, operational and strategic levels.

The author's research will show that a new communication architecture utilizing IP-based radios as the core component will allow the Marine Corps to develop into a adaptive force that can access greater amounts of data available via its connectivity to the GIG and as a result of its adoption of Network-Centric Warfare.

TABLE OF CONTENTS

I. INTRODUCTION 1
A. BACKGROUND 1
B. OBJECTIVES 2
C. RESEARCH QUESTIONS 5
D. SCOPE 5
E. METHODOLOGY 6
F. ORGANIZATION OF THIS THESIS 6

II. STATE OF EXPEDITIONARY MARINE CORPS COMMUNICATIONS 9
A. OVERVIEW OF CURRENT STATE 9
B. PROBLEMS WITH "AS IS" 10
C. CURRENT AND HISTORIC NETWORK ORGANIZATION 11
1. Need for Adaptation 11
2. Historic Sructure and Adaptability of USMC 14
3. A New Organizational Concept is Introduced 15
4. The Evolution of Distributed Operations 16
5. Distributed Operations in Afghanistan 17
D. DOCTRINAL DISTRIBUTED OPERATIONS DEFINED 20
1. Historical Context 20
2. New Organizational Concepts 22
3. Paradigm Shift 25
4. DO Communications Requirements 25
5. More Equipment Does Not Solve the Problem 27
E. PROBLEMS WITH CURRENT BANDWIDTH REQUIREMENTS 29
F. A BASELINE EXAMPLE 32
G. NEED FOR CHANGE 41

III. MESH NETWORKS AND DISTRIBUTED OPERATIONS 43
A. INTRODUCING A WIRELESS SOLUTION 43
B. REORGANIZATION OF COMMUNICATION FLOW 48
C. WIRELESS MESH DEFINED 49
D. PROS AND CONS OF WIRELESS MESH 51
1. Benefits of 802.11 and 802.16 Technologies in a Mesh Network 52
a. Self-forming 52
b. Physically Extends Traditional Networks 52
c. Peer-to-Peer Routing 52
d. Availability 53
2. Drawbacks to an 802.11 Mesh Network 53
a. Range 53
b. Security 53
c. Saturation 54
d. Conclusion 54
E. DISTRIBUTED OPERATION UNIT ASSUMPTIONS 54

1. Constraints 55
2. Requirements 56
3. Expected Capabilities 56
F. END-STATE: NETWORK-CENTRIC WARFARE 56
G. CONCLUSION 59
IV. ANALYSIS AND RESULTS 61
A. TACTICAL NETWORK TOPOLOGY 61
B. AVAILABLE EQUIPMENT 61
2. INTER-4 Micro Mesh Router (MMR) 64
C. C2 APPLICATIONS 65
1. Command and Control Personal Computer (C2PC) 65
2. Command and Control Compact Edition (C2CE) 65
D. ROUTING PROTOCOLS 66
1. Proactive MANET Protocols 67
2. Reactive MANET Protocols 67
3. Hybrid MANET Protocols 67
E. BENEFITS OF NCW TO THE WARFIGHTER 69
F. MATERIAL BENEFITS 73
G. CAPABILITY SETS 75
H. SCENARIO REVISITED 77
I. CONCLUSIONS 87
V. CONCLUSIONS 89
A. WHY FIX WHAT IS SOON TO BE BROKEN? 89
B. CONCLUSION 91
LIST OF REFERENCES 93
INITIAL DISTRIBUTION LIST 97

LIST OF FIGURES

Figure 1. CAP Organization circa 1968.....15
Figure 2. Frontal Attack.....21
Figure 3. Flanking Attack.....21
Figure 4. An infantry platoon organized into three squad-sized maneuver elements.....22
Figure 5. Chain Network.....23
Figure 6. All Channel Network.....24
Figure 7. DO Platoon Structure.....43
Figure 8. DO Communications Abstract.....44
Figure 9. DO Communications Architecture.....46
Figure 10. Command Communications Distribution.....47
Figure 11. Squad Communications Distribution.....47
Figure 12. Proposed DO Communications Architecture.....48
Figure 13. Basic Service Set.....49
Figure 14. Extended Service Set.....50
Figure 15. Basic Mesh Network.....51
Figure 16. Network-centric Warfare Vision.....57
Figure 17. The USMC concepts and NCW.....58
Figure 18. INTER-4 Tacticomp 6.....63
Figure 19. INTER-4 Tacticomp 5.....63
Figure 20. INTER-4 Tacticomp 1.5.....64
Figure 21. INTER-4 MRR.....65

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LIST OF TABLES

Table 1. Communications Equipment and Capabilities.....35
Table 2. Routing Protocols.....66
Table 3. Communications Equipment and Capabilities.....81

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ACRONYMS AND ABBREVIATIONS

AES	Advanced Encryption Algorithm
AO	Area of Operations
AODV	Ad-hoc On-demand Distance Vector
AP	Access Point
ARP	Address Resolution Protocol
(x)bps	Bits Per Second (K: Kilo, M: Mega, G: Giga)
BSS	Basic Service Set
C2CE	Command and Control Compact Edition
C2PC	Command and Control Personal Computer
C4	Command, Control, Communications, and Computers
CASEVAC	Casualty Evacuation
COP	Common Operational Picture
CONOPS	Concept of Operations
CS	Capability Sets
CSMA	Carrier Sense Multiple Access
COTS/GOTS	Commercial Off The Shelf/Government Off The Shelf
DARPA	Defense Advanced Research Projects Agency
DAMA	Demand Assigned Multiple Access
D-DACT	Dismounted Data Automated Communications Terminal
DISA	Defense Information Systems Agency
DO	Distributed Operations
DSR	Dynamic Source Routing
EPLRS	Enhanced Position Location Reporting System
ESS	Extended Service Set
ETCS	Expeditionary Tactical Communication System
FBCB2	Force Battle Control, Brigade and Below
GIG	Global Information Grid
GPS	Global Positioning System
IA	Information Assurance
IEEE	Institute of Electrical and Electronics Engineers

I-IM	Individual Information Management
IP	Internet Protocol
ISO	International Organization for Standardization
JTRS	Joint Tactical Radio System
KM	Knowledge Management
LAN	Local Area Network
LOS	Line of Sight
LPI/LPD	Low Probability of Intercept/Low Probability of Detection
MAGTF	Marine Air-Ground Task Force
MANET	Mobile Ad-hoc Network
MCTSSA	Marine Corps Tactical Systems Support Activity
MCWL	Marine Corps Warfighting Lab
MDACT	Mounted Data Automated Communications Terminal
MEA	Mesh Enabled Architecture
MMR	Micro-Mesh Router
NCOE	Network-Centric Operational Environment
NCW	Network-Centric Warfare
NLOS	Non-Line Of Sight
NM	Network Management
NSA	National Security Agency
NPS	Naval Postgraduate School
OFDM	Orthogonal Frequency Division Multiplexing
OLSR	Optimized Link State Routing
OSPF	Open Shortest Path First
OTH	Over The Horizon
OTM	On The Move
PCMCIA	Personal Computer Memory Card International Assoc
PDA	Personal Data Assistant
PKI	Public Key Infrastructure
PLI	Position Location Information
PtMtp	Point-to-Multipoint

PtP	Point-to-Point
QAM	Quadrature Amplitude Modulation
QDMA	Quadrature Division Multiple Access
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
SCR	Single Channel Radio
SINCGARS	Single-Channel Ground and Airborne Radio System
SIPRNET	Secure Internet Protocol Router Network
SNMP	Simple Network Management Protocol
SS	Subscriber Station
STAN	Surveillance and Target Acquisition Network
STEP	Standardized Tactical Entry Point
STS	Soldier Tactical Software
TDM	Time Division Multiplexing
T/E	Table of Equipment
T/O	Table of Organization
THHR	Tactical Handheld Radio
TOC	Tactical Operation Center
TNT	Tactical Network Topology
VAP	Virtual Access Point
VIRT	Valuable Information at the Right Time
VOIP	Voice Over Internet Protocol
WEP	Wired Equivalent Privacy
WiFi	Wireless Fidelity
WIMAX	Worldwide Interoperability for Microwave Access
WISP	Wireless Internet Service Provider
WPA	WiFi Protected Access
ZRP	Zone Routing Protocol

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I. INTRODUCTION

In modern warfare, the enemy is far more difficult to identify. No physical frontier separates the two camps. The line of demarcation between friend and foe passes through the very heart of the nation, through the same village, and sometimes divides the same family. It is a non-physical, often ideological boundary, which must however be expressly delineated if we want to reach the adversary and to defeat him.

Roger Trinquier[1]

A. BACKGROUND

In every endeavor, in each theatre of operation, in every clime and place, Marines need to communicate with their chain of command. The reasons are as manifold as the shifting winds, but the primary focus is to be connected to a network of commands that drive the fight and shape the battlefield. The tactical networks, as they are currently constructed, are established when the Marines come ashore, begin to prepare for combat, and are based upon an age-old paradigm that has not fundamentally changed since the first radio pair saw combat.

On the ground, the Marine Corps employs networks such as the Fire Support Coordination Center (FSCC) and its subordinate branches like the Force Fires Coordination Center (FFCC), the Air Support Section (ASS) and Target Information Center (TIC). Additionally, integration of new systems like the emerging Force XXI Battle Command, Brigade and Below (FBCB2) System within these networks in order to increase battlespace awareness. Systems like FBCB2 are

[1] Roger Trinquier, *Modern Warfare: A French View on Counterinsurgency* (London, England: Pall Mall Press, 1964), p.26.

digitized Battle Command Information Systems that are linked through Enhanced Precision Locating and Reporting System (EPLRS) and Single Channel Ground and Airborne Radio System (SINCGARS) tactical nets and providing better situational awareness (SA) while improving Command and Control (C2). Coordinating these is the Supporting Arms Coordination Center (SACC), which keeps artillery and naval gunfire from accidentally engaging friendly aircraft or friendly ground troops.

These tactical networks are defined and operated based on current Marine Air-Ground Task Force (MAGTF) doctrine and has as its backbone a suite of HF, VHF, and UHF radio sets[2]. Current technologies are being stretched to the limits of physics and various coding schemes are emerging to try and squeeze out more room on an already crowded Electro-Magnetic (EM) spectrum. A paradigm shift in communication equipment is required which calls for an architecture of technologies, whose protocols allow for expansion, the unique identification of recipients, and the ability to talk to one person or all persons on the network.

B. OBJECTIVES

The implementation of the Goldwater-Nichols Act of 1986 compelled the armed forces to rethink their core operating concepts in an effort to focus them on becoming more synchronized with the developments of their parallel service and future concepts. According to some experts, "the largest problem for security force is how to control

[2] MCWP 3-40.1, *Marine Air-Ground Task Force Command and Control*, (Washington D.C.: Government Printing Office, 2003) p.8-1.

vertical organizations in an increasingly horizontal world. The military service - Army, Navy, Air Force and Marines - are essentially vertical organizations with clearly defined roles and missions. With the advent of air power, the lines become blurred and the need for jointness - the horizontal - increased sharply."[3] The need for a new paradigm communication architecture going from the Napoleonic hierarchy to one based on the needs of information flow is an absolutely critical requirement associated with this "horizontal" shift. This groundbreaking shift will also assist in the eventual transition of the Marine Corps toward its goal of being a viable part of a Network-Centric force.

This thesis is intended to explore the feasibility of a tactical network, based upon a mesh topology such as Mobile Adhoc Networks (MANET)[4], as it applies to disparate organizational structures. Currently, the United States Marine Corps is experimenting with a concept that increases the distribution of traditional forces across the modern battlefield. This concept is known as Distributed Operations (DO). The concept of DO attempts to maximize the Marine Air-Ground Task Force (MAGTF)[5] Commander's ability to employ small tactical units across the depth and breadth of a nonlinear battlespace in order to achieve favorable intelligence-driven engagements as part of the

[3] Denis J. Quinn, ***The Goldwater-Nichols DOD Reorganization Act: A Ten-Year Retrospective***, (Washington, DC: National Defense University Press, 1999), p.3.

[4] ***MANET Charter***, Apr 7, 2007, <http://www.ietf.org/html.charters/manet-charter.html> (last accessed Aug 28 200).

[5] GlobalSecurity.Org, ***MAGTF***, Apr 6, 2006, <http://www.globalsecurity.org/military/agency/usmc/magtf.htm> (last accessed Aug 28, 2007)

Joint Force Commander's overall campaign[6]. The USMC has further developed the concept of employing DO units, which are commonly platoon sized elements, from within its traditional infantry battalion as an additional capability within the force. This affords the commander the ability to use the force as an additive and scalable capability that exists within the framework of a currently fielded infantry battalion.

The objective of this research is to illuminate current challenges, as well as the future benefits derived from deploying a ubiquitous MANET which contains the hallmarks of a mesh, namely self-awareness, self-healing, scalability, and routability within widely dispersed combat organization similar to a DO unit. This thesis will also address the network and the command structure as it relates to Network-Centric warfare.

According to MCDP 1-2, ***Campaigning***, "the conduct of a successful campaign requires the integration of many disparate efforts. Effective action in any single warfighting function is rarely decisive in and of itself. We obtain maximum impact when we harmonize all warfighting functions to accomplish the desired strategic objective in the shortest time possible and with minimal casualties."[7] We ensure thorough coverage throughout the breadth of the battlefield by focusing the context of the campaign on six

[6] Marine Corps Warfighting Lab, ***Questions and Answers About Distributed Operations***, Mar 16, 2005, p.1.

[7] MCDP 1-2, ***Campaigning***, (Washington, D.C.: Government Printing Office, 1997) p.76.

major functions: command and control, maneuver, fires, intelligence, logistics, and force protection.[8]

The authors do not intend this thesis to be a panacea for the Department of Defense efforts in finding a wired/wireless solution to the tactical internet. This is merely the exploration of one possible solution. There are several assumptions that are made in the research conducted, which will be explained in due course.

C. RESEARCH QUESTIONS

The primary research question deals with a fundamental shift in the communications equipment paradigm within the Marine Corps. How will going from a voice-based, push-to-talk device to a much more sophisticated IP-based device that is capable of delivering voice communications, as well as providing data serve the needs of the Marine Corps? What are the warfighting benefits that the Marine Corps can achieve as a result of adopting an IP-based communications system?

D. SCOPE

The scope of this thesis is left intentionally wide to enable follow-on research and to allow other researchers to vary the methods and ideas to develop multiple courses of action. This is truly the only way to present a viable solution to the ultimate users of this research, the United States Marine.

[8] MCDP 1-2, ***Campaigning***, (Washington, D.C.: Government Printing Office, 1997) pp.76-91.

E. METHODOLOGY

The methodology includes extensive research of available literature, both hard copy and electronic, on underlying MANET theory, the Tactical Internet (TI) being developed and deployed by the United States Army, and information gathered on the Global Information Grid (GIG). Additionally, the authors focused on the historic data associated with the Marine Corps Company (and below) tactical assets. The authors sought out diverse sources in order to strengthen their knowledge on the various facets of wireless mesh networks. The authors consulted public as well as private resources, both academic and proprietary, published proceedings of standards organizations, and pioneers in the field. Some of the most extensive research and discovery was gathered from the Tactical Network Topology (TNT) experiments conducted by Dr. Alex Bordetsky at Camp Roberts, CA.

F. ORGANIZATION OF THIS THESIS

The organization of this thesis is as follows:

Chapter I consists of the introduction and the abstract. In this section the authors have laid out the background, objectives, research questions, scope and methodology.

Chapter II discusses the current situation, historic events, and the problems faced by Marines when trying to communicate across multiple networks (radio, not computer networks). The authors shall present an example of a generic DO platoon and the communications equipment that they will typically carry into combat. The scenario shall

be developed to demonstrate how they would communicate between themselves as well as with higher headquarters.

Chapter III introduces the current communications architecture of DO organizations and will cover a brief definition of wireless and mesh networks, to include advantages and disadvantages of each, and how they should be adapted into a new communications architecture that provides for connectivity to the GIG.

Chapter IV will introduce existing technologies and highlight the benefits of utilizing these devices, outline the benefits of why the Marine Corps needs to adopt an architecture that utilizes these emerging technologies, and some recommendations for ways to reorganize and improve communication flow.

Chapter V lists conclusions from research conducted within the current state of technology, the scenario introduced in Chapter II will be reviewed with these benefits in focus. Recommendations for future research will also be included in this section.

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II. STATE OF EXPEDITIONARY MARINE CORPS COMMUNICATIONS

Today's scientists have substituted mathematics for experiments, and they wander off through equation after equation, and eventually build a structure which has no relation to reality.

Nikola Tesla[9]

A. OVERVIEW OF CURRENT STATE

Communication Marines are tasked with the daunting mission of managing all of the applications (email, C2 systems) that Marines are so increasingly dependent upon in both the field and in garrison. Each communications Marine receives their basic training in communications school so they can differntiate between HF, VHF, and UHF radio sets. After this initial schooling, they go through on the job training to learn how things are really done.

Despite years of doing this, we reinvents the wheel with each exercise, operation, or combat action. Radio nets are established, tested, broken, and re-established in order to maintain constant communications. Within the last few years, communications Marines have had new technologies to deal with that increase their repertoire to include routers, switches, Domain Name Server (DNS), Exchange Servers (mail), Local/Wide Area Networks (LAN/WAN), and Internet Protocols (IP)[10]. They create and manage email accounts, connect (and disconnect) computers into the

[9] Nikola Tesla, *Modern Mechanics and Inventions, July, 1934*

[10] When discussing or referencing IP the authors are specifically talking about packet switching networks.

network, and establish internet connectivity, file services, Intrusion Detection Systems (IDS), and firewalls. Truly, they are the telecommunications Jack of All Trades.

What is missing in this picture is a constant framework or architecture that can be relied upon to supply a backbone from which to grow. A radical movement from U/V/HF radio communications to IP based radio communications lends itself to greater flexibility with, at the very minimum, the same reliability of service as is currently being seen. What the IP paradigm allows is the ability to speak anywhere to one or all persons on the network, instead of the only option with current radios, and talking to everyone, no matter what.

B. PROBLEMS WITH "AS IS"

Virtually every communications officer in the military knows that a storm is approaching the horizon; meaning that the limited RF spectrum is being utilized by more and more people and eventually the camel's back will break with the addition of one more straw. [11] As operations grow in scope, communicators are being called upon to provide increasing detail to commanders that wish to know what is causing rifleman Dodd to take Course of Action (COA) A as opposed to COA B, and they seek a granularity that radio networks were never intended to bring. Further, since the total number of conversations possible is n-1, the possibility of a collision is increasingly closer to 100%.

[11] "The electromagnetic spectrum is an increasingly limited resource. Most likely without proper management the electromagnetic spectrum will quickly reach saturation and will seriously degrade mission performance." FM 24-2 Spectrum Management

Another problem with traditional radio networks is that while one person gets to talk the remaining personnel on the network can only listen, even if there is only one intended recipient. First come, first served is the rule of the day with no regard to importance or urgency of the specific traffic or the person sending that traffic. Communications in these instances are susceptible to being stepped on when another user keys the microphone, and confusion and ambiguities are injected into the equation when the intended recipient does not know that they are the receiver of a communication stream. Time and resources are wasted in clarifying directed communications. [12]

C. CURRENT AND HISTORIC NETWORK ORGANIZATION

1. Need for Adaptation

Before discussing the technological aspects of this problem, certain historic organizational biases must be addressed. Resolving issues associated with communication architecture only addresses a small percentage of the problem the Marine Corps will face in the coming decades. The Marine Corps must also address the aging state of its tactical units. Well before the Vietnam War, infantry units attempted to re-organize their linear and archaic structure to better meet the needs of the combat leader and the warfighter. The reorganization of these units was often driven by the organization of the enemies combat

[12] Clayton Craig and Chris Tsirlis. ***Command and Control for Distributed Operations,*** Master's Thesis, Naval Postgraduate School, June 2007. Research conducted validated the bridging ability of current technologies to bridge the gap between legacy systems and packet switch systems. The authors identify that this is a viable short-term solution and does not meet the long-term goals of the Marine Corps and the DoD as a whole.

units. The driving factor was often an attempt to avoid fighting the last war's adversary.

Mark Richter, Program Manager for the Marine Expeditionary Rifle Squad (MERS), at Marine Corps System Command (MARCORSYSCOM), indicates that the Marine Corps has made enormous strides in redefining the infantry squad as a system. In contrast, the Army feels that the individual soldier is the system (Land Warrior) [13] that must be re-defined. [14] The reason this is so germane is because both the Army and the Marine Corps have identified that the communication nodes and how the communication flow will flesh out is essential in the development of a proper communication architecture for future communication systems which must be adopted by the DoD.

Whether communicating between individual units or coordinating fires for adjacent units or for themselves, the flow of information and adaptability of small units operating in this network allow for rapid transitions between missions and an ability to respond quickly to emerging threats. For command and control, all channel networks are conducive to the dissemination of orders and the passing of reports because of their inherent overlap of nodes. This design makes the enemy extremely adaptive and requires friendly forces to react to their tighter decision loop.

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[13] Military Analysis Network, ***Land Warrior***, Aug 7, 1999, <http://www.fas.org/man/dod-101/sys/land/land-warrior.htm> (last accessed Aug 28, 2007)

[14] Mark Richter (Program Manager MERS, MARCORSYSCOM), interviewed by Chris C. Curran, request for information on the MERS Program, July 22, 2007.

According to John Arquilla, Professor, Department of Defense Analysis at the Naval Post-graduate School, "Hezbollah conducted five weeks of what many would label as extremely effective combat operations against the Israeli Defense Force (IDF). The IDF is considered to be a superior fighting force, yet Hezbollah fighters were able to effectively battle this larger conventional force using tenets of the DO concept."[15] From July 12, 2006 until August 14, 2006, Hezbollah forces distributed throughout Lebanon battled the IDF long enough to bring cessation of combat operations and political victory.[16]

As discussed above, the external environment in which close-in-combat will take place has changed dramatically in the last decade. It is therefore paramount that the current mature structural organizations of the USMC ground forces utilize adaptation to defeat the enemy and their organizational structure. The USMC organizational strategy must be adapted to promote mission success through an enhanced warfighting capability, increased force protection, and an ability to provide for physical sustainment of numerous widely disbursed decentralized combat units.

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[15] Naval Postgraduate School, October 11, 2006, class lecture.

[16] Derived from: Israel Ministry of Foreign Affairs, ***Winograd Inquiry Commission***, Apr 30, 2007, <http://www.mfa.gov.il/MFA/Government/Communiques/2007/Winograd+Inquiry+Commission+submits+Interim+Report+30-Apr-2007.htm> (last accessed Aug 28, 2007)

2. Historic Sructure and Adaptability of USMC

The Marine Corps, for their part, has identified this weakness in the current force structure and is working hard to lead the US Military in the organizational race to counter the insurgent network. Historically, whether defeating the underground fortifications during the island hopping campaigns of World War II, the implementation of vertical lift and close air support aircraft during the Korean conflict, or the successful integration of the Combined Action Platoons (CAP) in Vietnam, the Marine Corps has always considered itself as visionary and a front runner in adapting and countering an emerging foe.

Recognizing the threat associated with combat in the jungles of Vietnam, the USMC initiated the CAP program which forced the traditional rifle platoon to be deconstructed from the linear structure and dispersed in hamlets throughout the jungles of Vietnam. This dispersion of platoon-sized forces throughout the depths and breadths of a non-linear battlefield limited the enemy's ability to maintain any semblance of preeminence on the non-linear battlefield. By disbursing squads of Marines, who were combined with elements of the South Vietnamese Popular Forces (PF's), and requiring them to live among them in the surrounding villages, the CAP concept came into being. As a result, the Marines expanded, tested and evaluated the concept and found it to be effective in countering Viet Cong influence and control of the local area. [17]

[17] William Go, ***The Marine Corps' Combined Action Program and Modern Peace Operations - Common Themes and Lessons,*** USMC Command and Staff College, 1997, p.9.

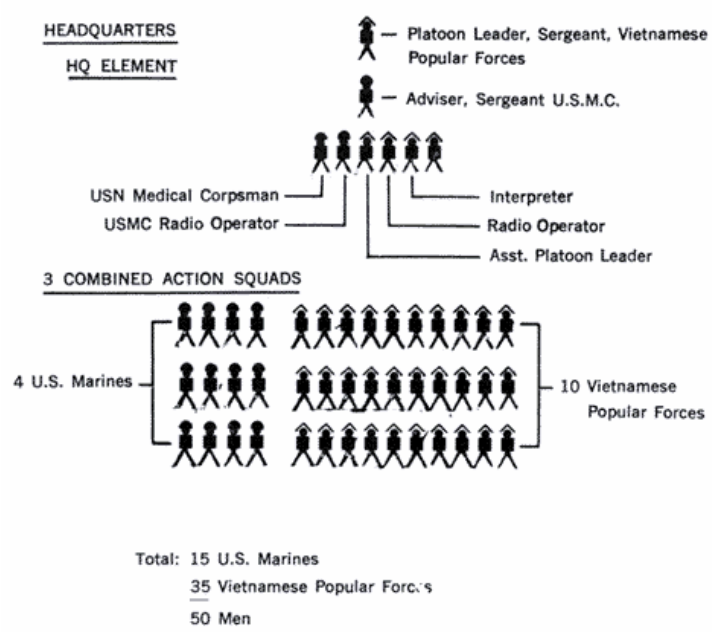

Figure 1. CAP Organization circa 1968[18]

3. A New Organizational Concept is Introduced

Today, the USMC continues to experiment with arming and equipping small units that are designed to dominate the battlefield using infestation[19] or swarming warfare. [20] The USMC refers to this concept as "distributed operations" (DO). DO, simply put, is the use of platoon sized units ashore which have transitioned away from the chain network and formed itself as an all channel network[21]. The DO platoon remains connected through technology, lethal through integrated fires, and capable through increased

[18] Brooks Brewington, ***Combined Action Platoons: A Strategy for Peace Enforcement,*** USMC Command and Staff College, 1997, p.34.

[19] Gary W. Anderson, "Implementing OMFTS: Infestation and Investation," ***Marine Corps Gazette,*** April 1995, p.57.

[20] John Arquilla and David Ronfeldt, ***Swarming & The Future of Conflict,*** (RAND, 2000), p.7.

[21] Naval Postgraduate School Brief, Nov 20, 2006, lecture, ***Technology Change and Networks,*** dated 3 November 2003, slide 9 of PowerPoint brief by Deborah Gibbons.

training at all levels. The DO concept equals any cutting edge adaptation in the history of the Marine Corps and is the right fix at the right time. The DO organization will be defined in greater detail in chapter III.

4. The Evolution of Distributed Operations

The DO concept was formally introduced and adopted soon after the USMC's unprecedented tactical successes during the bloody battle for Fallujah, Iraq, in November 2004. During Operation AL-FAJR, in Fallujah, Iraq, countless Marines were skillfully led by their small unit leaders who capably executed high intensity conflict operations within the non-linear, urban battlefield. More remarkable was the small unit leader's ability to lead these marines in much greater decentralized environments than ever imagined possible. According to General Michael W. Hagee, the former Commandant of the Marine Corps (CMC), Operation AL-FAJR validated and further solidified the needs and tenets of the DO concept. In response to the type of warfare his Marines were engaged in, General Hagee provided guidance on the further definition and experimentation with the concept of DO [22].

The DO concept meets the needs for a force that can operate independently within a non-linear battlefield while still being able to function in traditional infantry roles on order. The Marine Corps Warfighting Lab (MCWL) officially implemented what had been only an experiment in recent years. Within a year of the current Global War on

[22] Michael W. Hagee, "ALMAR 018/05," Apr 18, 2005, <http://www.usmc.mil/almars/almar2000.nsf/52f4f5d11f10b4c4852569b8006a3e35/35a74723d7bcc61085256fe70061040a?OpenDocument> (last accessed Aug 28, 2007).

Terrorism (GWOT), DO units were conducting decentralized combat operations in Afghanistan. The ability to make this fundamental shift in warfighting techniques ensures the USMC will remain the force in readiness that it has always been. With the development of DO, the Marine Corps will have an additive, lethal capability inherent to its current force structure. General Hagee summarizes his plan in the following quote:

> While ever ready to respond to major combat operations, the future holds a greater likelihood of irregular wars fought in urban environments, against thinking enemies using asymmetric tactics. Thus, we will adapt our tactics, techniques, and procedures as well as technology to enhance our capabilities to succeed in these environments.[23]

5. Distributed Operations in Afghanistan

Since the beginning of the GWOT, two infantry platoons have been designated as DO Platoons. The first from the 3rd Marine Regiment in Kaneohe Bay, Hawaii, and the other from the 5th Marine Regiment out of Camp Pendleton, California. The first was a platoon from 1st Battalion, 3rd Marines and the second was a platoon from 1st Battalion, 5th Marines.

Since the inception of the DO model, only the 1st Battalion, 3rd Marine Regiments DO Platoon has seen combat. The DO Platoon from 1st Battalion, 3rd Marine Regiment proved its worth during the battalion's five month deployment to the Kunar Area of Northern Afghanistan.

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[23] Carl Desantis (Platoon Commander, DO Platoon, 1st battalion, 3rd Marines) Interview by Mr. Peter Dotto, Marine Corps Center For Lessons Learned, Jul 19, 2006.

The "Lava Dogs" of Task Force Chosin were able to employ their DO Platoon exactly how the CMC and MCWL envisioned the unit being used. Their primary missions in Afghanistan were traditional in nature, but the geographic area that the DO platoon covered was far greater than any other infantry platoon had ever controlled in the past. During an interview on 19 July 2006, the DO Platoon Commander from 1st Battalion, 3rd Marines stated that "I was assigned by one of their Company Commanders – sort of an AOR and it was about three clicks by one click and so I just gave every Squad a one click by one click area…" on another mission, the platoon "had a huge area with about six clicks of road to protect from IED emplacement and we were spread out quite a bit. We were able to be spread out higher than 500 meters…" and cover the entire six clicks.[24]

As a result the DO Platoon and the DO concept received high reviews for its lethality and extreme adaptability. According to MCWL brief to MajGen Natonski, the Commanding General, 1st Marine Division, the DO Platoon from 1st Battalion, 3rd Marine Regiment was able to execute numerous missions to exacting specifications:

> On 25 Jan 06, the DO Platoon conducted a foot mobile security patrol along high ground SE of the base camp. During the course of this patrol, a friendly convoy was attacked by IED, heavy small arms, and mortars. The convoy commander was unable to maintain communications with the COC or indirect fire agencies. The DO Platoon initially relayed all communications (calls for fire, SITREPs, CASREPs etc.). Ultimately, the DO Platoon Commander (trained and qualified as a JTAC during LOE-1) took control of close air

[24] Carl Desantis (Platoon Commander, DO Platoon, 1st battalion, 3rd Marines) Interview by Mr. Peter Dotto, Marine Corps Center For Lessons Learned, Jul 19, 2006.

> support and coordinated MEDEVAC. It should be noted that the "DO communications suite" at the platoon headquarters facilitated his ability to do this.
>
> On 25 Feb 06, several observation posts from the DO Platoon were able to provide azimuths to a source of enemy fire. The DO Platoon CP triangulated the data and called in an effective fire mission. Tactical land navigation was a key ingredient of SUET. During the course of this incident, intra-platoon communications was disciplined and effective using the PRR, allowing units to share situational awareness in a timely fashion. [25]

During combat operations in the Korengal Valley outside Jalalabad, Non-commissioned Officers (NCO) and junior officers of the DO Platoons skillfully executed operations that were normally the responsibility of more senior Marines. Until recently, the delivery of Close Air Support (CAS) ordnance was commonly authorized by a Marine Aviator serving as a Forward Air Controller (FAC). The FAC serves with dismounted infantry units within his parent battalion. Within the DO concept, a Lance Corporal or Corporal theoretically would be able to properly and lethally employ close air support to defeat enemy forces within his fire team battle space. This is accomplished by exacting training and the pushing of technology down to the Marines in the trenches.

The ability of 1st Battalion, 3rd Marines DO Platoon to have numerous decentralized teams led by highly trained and "wired" Marines that were operating within a non-linear battlefield validated the current vision of DO concept.

[25] Carl Desantis (Platoon Commander, DO Platoon, 1st battalion, 3rd Marines) Interview by Mr. Peter Dotto, Marine Corps Center For Lessons Learned, Jul 19, 2006.

Simply translated, DO means that skilled and technically apt NCOs and above will be required to execute missions and skill sets that have historically been the responsibilities of company grade officers and above.

D. DOCTRINAL DISTRIBUTED OPERATIONS DEFINED

1. Historical Context

Throughout the documented history of armed conflict, the linear and hierarchical organization of infantry units has remained largely unchanged. Roman leaders utilized linearly organized armies against the Gauls in 295 BC and for the subsequent two-hundred and thirty years. In 65 BC the Roman army drastically reorganized their field armies following the battle of Marius in order to maintain the Roman army as the preeminent military force in the world.

Linear combat using tactics similar to those depicted in Figures 2 and 3 have been utilized to defeat an adversary for centuries and are considered historically validated combat techniques. These designs were established as doctrine and were continuously reutilized and modified by countless subsequent armies to provide leaders with the greatest and most lethal tactics needed to defeat their enemy.

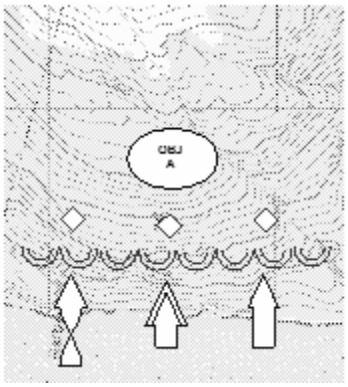

Figure 2. Frontal Attack[26]

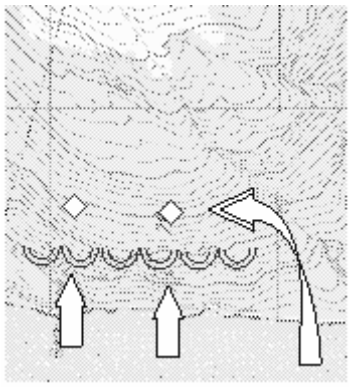

Figure 3. Flanking Attack[27]

In the early 16th Century, Napoleon Bonaparte mastered the use of a hierarchical organization and managed to achieve an unprecedented level of command, control and oversight of his huge army, but Napoleon's enemies did not evolve as rapidly as his army did. As a result, little change was required and for hundreds of years a status quo remained within the infantry organizational structure. Similarly, the United States Marine Corps (USMC) has continued to conduct offensive operations using linearly

[26] Naval Postgraduate School, Nov 7, 2006, lecture, "Offensive Operations: Warfighting from the Sea (MAGTF Operations)", slide 6 of PowerPoint brief.

[27] Ibid, slide 7 of PowerPoint brief.

organized combat platoons and squads that closely resemble Figure 4 from its inception in 1775 to as recently as the 2003 invasion of Iraq.

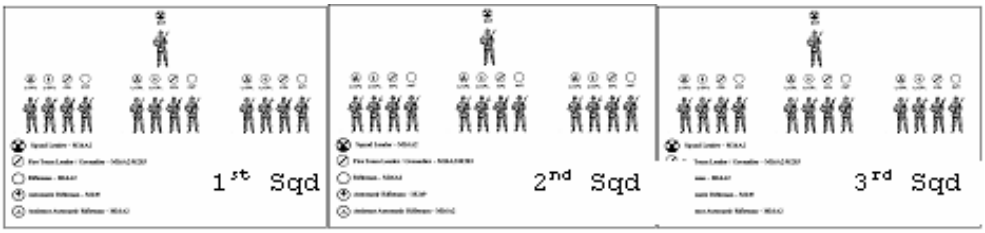

Figure 4. An infantry platoon organized into three squad-sized maneuver elements[28]

2. New Organizational Concepts

As discussed in earlier paragraphs, the doctrine employed by today's military leaders has remained largely unchanged in form and function even though the enemy and the battlefields have changed immensely. Currently, the vast majority of friendly forces are conducting daily combat operations with only a slight deviation from the traditional organizational structure used during the campaigns of World War II. With little deviation, the USMC continues to operate on the modern non-linear battlefield utilizing tactics that are best suited to a very linear battle. Figure 5 illustrates the chain network which is the most common structure of the conventional units operating abroad. This restrictive structure is extremely linear and often slow to respond to emerging threats. While operating with this standard hierarchical organization, friendly forces cannot effectively counter the enemies' well dispersed and decentralized structure.

[28] FMFM 6-5, ***Marine Rifle Squad,*** (Washington, D.C.: Government Printing Office, 1991), pp.1-3.

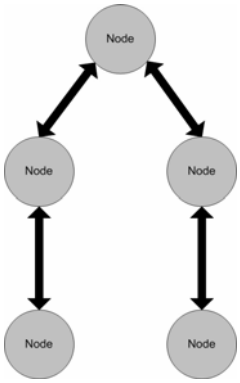

Figure 5. Chain Network[29]

The chain network is a restrictive structure best utilized when the threats are linear and the force is of a centralized nature. This network is vulnerable because of its inability to adapt and respond to emerging threats. While operating within this standard hierarchical organization, friendly forces cannot effectively counter the enemies' well dispersed and decentralized structure. Because of the restrictive nature of this network, friendly forces often find themselves overloaded with information and too often unsure what to do with it. Additionally, with an inability to properly disseminate information, members of this network can often only function under the last given order provided by their leader. The ability to operate in absence of orders on a decentralized battlefield is not an inherent weakness, but rather it is a skill set that should be embraced. The rigid chain network is no longer conducive to the modern battlefield and contains numerous limitations that must be addressed in order to facilitate success in modern war.

[29] Naval Postgraduate School Brief, Nov 20, 2006, lecture, ***Technology Change and Networks,*** dated 3 November 2003, slide 9 of PowerPoint brief by Deborah Gibbons.

It is widely understood that the structure conventional forces face on a daily basis is similar to the all channel model or the hub and spoke design. Figure 6 shows the communication and control coordination structures used by non-conventional enemies such as the Irish Republican Army (IRA), Viet-Cong, and the National Liberation Front (FLN), comprising a hybrid command network which enables their high-level of flexibility and adaptability. The self-synchronizing and self-healing networks in use today by coalition adversaries are not a new design or a new concept. Quite the contrary, these networks have been employed by countless opposition forces attempting to gain leverage against the hierarchical and linear networks used by conventional US Military forces like the USMC.

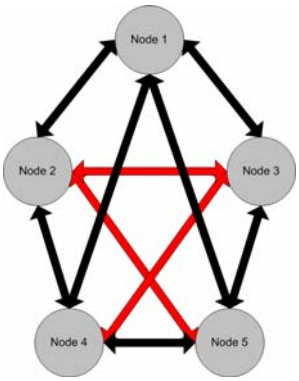

Figure 6. All Channel Network[30]

[30] Naval Postgraduate School Brief, Nov 20, 2006, lecture, ***Technology Change and Networks,*** dated 3 November 2003, slide 9 of PowerPoint brief by Deborah Gibbons.

3. Paradigm Shift

Distributed Operations (DO) emerged as a response of the Marine Corps initiative to shift the way in which it will fight future conflicts. Taking the notion of small unit maneuver warfare to a natural conclusion, DO attempts to address non-linear warfare by utilizing a robust command and control communications architecture in remote, even disparate localities, taking advantage of the autonomy provided each platoon and emphasizing dispersion and independence in their highly trained leadership.

The baseline concept of DO is the ability to maximize the Marine Air-Ground Task Force (MAGTF) commander's ability to employ tactical units across the depth and breadth of a non-linear battlespace in order to achieve favorable intelligence-driven engagements as part of the Joint Force Commander's overall campaign[31].

4. DO Communications Requirements

The non-linear nature of the Distributed Operations (DO) concept requires a refocusing of the task requirements for USMC ground operating forces including vital functional areas like Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR), Maneuver and Fires (M & F), Logistics and Force Protection (L & FP), and Human Performance, Training and Education (HPT&E).

Command and Control within a traditional infantry platoon is extremely centralized. The DO concept intends

[31] Marine Corps Warfighting Lab, Project Sea Viking 06, webpage, Questions and Answers About Distributed Operations, dated 20 March 2005 <http://www.mcwl.usmc.mil/SV/DO%20FAQ%2016%20Mar%2005.pdf>

to introduce a much more fluid and decentralized architecture that allows the small unit leader to take independent actions in absence of information from his superior based on what is happening to his unit at that exact time.

The tactical control and maneuver of infantry operations within a traditional infantry platoon is normally orchestrated by either a mid-level squad leader or platoon sergeant based on the guidance of the platoon commander. As a result, maneuver and tactical actions can often times be disseminated in a very specific and exacting manner from leader to subordinate. Due to the distributed nature of the DO concept, the ability to control the maneuver of a small unit must be disseminated to the lowest level possible to ensure exploitation of opportunities.

For the DO concept to succeed, maneuver must be conducted in concert with fires. Traditionally, fires are controlled by the platoon commander and on occasion a mid-level squad leader, and are often extremely bottlenecked at the higher headquarters making them unresponsive. The fire support plan is generated in advance and pushed down to the mid-level leader for use when the resource becomes necessary. As described before within the DO concept M & F must be executed in concert, therefore requiring the junior leader be able to safely conduct fires (indirect or direct) within a decentralized DO structure. This means that fires must be available from non-organic units at his command, therefore requiring bottom up fire support.

The resupply of expended ammunition, food, or water across a dispersed battle field will remain one of the most

demanding challenges of the DO concept. Logistics and Force Protection (L & FP) must follow along a very similar path as M & F. L & FP will force leaders and planners to transition from top-down logistical approach to a bottom-up approach if the dispersed force is to remain effective.

Lastly is the need for increased Human Performance, Training and Education (HPT & E). HPT & E is crucial for the success of this concept. The ability to survive on energy producing sustenance is one thing, but the ability for a junior leader (19 to 20 year old) to be capable of coordinating fires with maneuver and re-supply is an impressive theory. The leader will have to attend numerous training and education institutions, to meet the rigors of his promotion to team leader. HPT & E must remain in tune with the organizational change.

5. More Equipment Does Not Solve the Problem

With each new technology that comes along, commanders are quick to see it as a solution to the problem of limited spectrum availability or limited bandwidth. This is a flawed but understandable mentality given that no true plan on where the Department of Defense is headed with respect to long-term communications and data transmission exists. What develops is an excess of radios, but no way to talk to the platoon three kilometers away because the net is inundated. The typical solution is simply to add more radios to the mix, and the dog continues to chase its tail. Not realizing that a solution is close at hand, most combatant commanders will continue with the standard model until given reason to change.

Enter satellite communications (SATCOM). SATCOM has been around since Sputnik began to beep from orbit in 1957. The ensuing space race has brought us marvelous new constellations of artificial stars that stream data around the globe, providing tele-communications 24/7. Humans have responded by wanting more, but there is only so much to go around.

There are several issues with satellite communications. First, satellites are expensive to build and put on orbit. Second, once they are built, maintenance is virtually impossible (the Space Shuttle not withstanding). Third, the technology of the satellite stops upon launch, meaning you cannot upgrade to bigger, better satellites, you must replace them. These older systems are what are being using to try and meet the ever-increasing demands of commanders around the world.

The age old altruism that need always exceeds capacity is never more true than today; tactical networks are becoming overburdened with an ever-increasing number of users and applications as the need for information grows faster than the networks can provide. "At the peak of [OIF I], DISA claimed that 3 Gbps of satellite bandwidth was being provided to the theater,… 30 times the bandwidth made available during Desert Storm."[32] A typical satellite connection to a Standardized Tactical Entry Point (STEP) is 1024 kbps. This is multiplexed to provide Defense

[32]Joe Leland and Isaac Porche III, ***Future Army Bandwidth Needs and Capabilities,*** (RAND, 2004) p.11.

Information System Network (DISN) services[33] to many tactical users. After being distributed into separate services, the data networks only receive a portion of the bandwidth, typically less than 384 kbps. To illustrate the issue with this, one need imagine the problem of watering an entire herd of horses from a garden hose. In addition, due to the adverse effects that high bit errors and latency associated with satellite transmissions cause for TCP (Transmission Control Protocol), actual traffic throughput capability is even less than the allotted bandwidth. Bandwidth is the limiting factor.

E. PROBLEMS WITH CURRENT BANDWIDTH REQUIREMENTS

The overarching issue of growing requirements has not fallen on deaf ears and senior leadership is addressing the problem almost daily. They are attempting to bridge the old world with the new by introducing various COTS solutions and technologies, leasing more bandwidth on commercial SATCOM, or even utilizing various WAN acceleration products. However, due to proprietary constraints, most of these acceleration devices are incompatible with other commercial products causing interoperability issues when disparate units purchase different optimization solutions. During OIF I, MARCENT purchased SkyX accelerators to establish an Intel link between 3rd Marine Air Wing and 1st Marine Expeditionary

[33] DISN services normally extended to the Division COC include: Digital Trunk Group (DTG) for secure and non-secure telephone service from the Defense Switched Network (DSN), Secure Internet Protocol Router Network (SIPRNET) and Unclassified but Sensitive Internet Protocol Router Network (NIPRNET), and Video Teleconference (VTC).

Force (I MEF) [34], the 24th Marine Expeditionary Unit (MEU) purchased Expand accelerators, and the STEP sites implemented the ComTech Turbo IP Accelerators (I MEF also had Expand Accelerators). Each of these products used different protocols at that time, which were not interoperable and limited to internal point to point links with devices produced by the same manufacturer on each end. Despite significant performance increases observed on internal links, links to adjacent units, Joint Task Force (JTF) elements, and the STEPs remained congested due to incompatible proprietary standards. A unified architecture and uniform protocol would resolve these very germane conflicts, which is the salient point of this thesis.

Another solution to increasing bandwidth, which is all too often the solution first opted for, is to simply buy more, which has proven to be inordinately expensive. There is only so much commercial space available, and the commercial satellite industry's interests are not always the same as ours. Additionally, the very nature of DO puts them well beyond the range of standard communications where the only reachback is satellite telephones such as the Iridium or Support Wide Area Network (SWAN).

During a 2006 Distributed Operations Architecture Study (DOAS) conducted by Defense Advance Research Project Agency (DARPA) it was determined that "[t]he assessment found that the near-term USMC platoon legacy communications technology cannot support the requirements estimated for MANET because the DO unit operating in a Net-centic environment has a very large aggregated message generation

[34] LtCol Mark Bryant, "FW: Request For Information," Oct 13, 2004, personal email (Aug 28, 2007).

rate (on the order of 250,000 bps). Similarly, the Enhanced Position Location Reporting System (EPLRS) and Single-Channel Ground and Airborne Radio System (SINCGARS) are not adequate to the message generation rate requirements. EPLRS will satisfy point-to-point requirements, but cannot do so when used as the communications backbone." [35] This is where the authors believe the US Army and US Marine Corps' communications architectures make their point of demarcation.

The Army had developed the Land Warrior System to meet their paradigm of the individual soldier as a system based on the use EPLRS as the C2 backbone; although the US Army recently cancelled the Land Warrior System, [36] the 4th Stryker Brigade Combat Team deployed to Iraq with this inadequate system. The Marine Corps for their part has identified this weakness (EPLRS as the backbone for a C2 system), but as yet has not identified a viable solution. The authors submit that an IP-based communication suite will provide the most robust and feasible answer to this problem. Furthermore, DOAS has specifically addressed the inherent weakness of EPLRS system as a C2 system.

> Grouping Platoon Commander and the Squad Leader nodes into a series of local area networks reduced maximum nodal loads. However, even with this reduced load, the near-term USMC Distributed Operations platoon legacy communication technology is not adequate for the estimated requirements. As before, EPLRS (as backbone to

[35] DARPA, ***Distributed Operations Architecture Study (DOAS)*** (DARPA, 2006), p.21.

[36] ***Stryker Brigade News***, Aug 29, 2007, <www.strykernews.com/archieves/2007/02/07/land_warrior_fu.html> (last accessed Aug 28, 2007)

the network) and SINCGRS are not adequate for the message generation rate requirements. [37]

F. A BASELINE EXAMPLE

In order to demonstrate the issues that the Marine Corps is facing with regard to what is being discussed, the authors propose a generic model of a Distributed Operations (DO) platoon. The authors will establish a baseline or "as is" condition based upon current constructs and communications protocols, illustrate the difficulties faced when operating in a distributed environment and still trying to remain linked to the networks, and then present an alternative solution that capitalizes on current technologies, provides for expansion, retains clear voice communications, and introduces data into the networks for such things as maps and biometric files, and video feeds.

Building upon already proven technologies and research conducted at the Naval Postgraduate School, as well as commercial endeavors, the authors will construct an improved DO platoon enabled to conduct operations unambiguously, able to feed data to adjacent and higher units, keep constant location updates, and provide raw video to decision makers at all levels.

The following scenario was derived from requirements provided in the MCWL "Distributed Operations 2006 Capabilities and Enhancement Report" and "Questions and Answers about Distributed Operations" and will be used to details shortfalls of the current communication system.

[37] DARPA, ***Distributed Operations Architecture Study (DOAS)*** (DARPA, 2006), p.22.

0330 14 October, after pre-combat checks, a platoon-sized unit departs and travels west out of Al Haqlaniyah in the Anbar province of Iraq enroute to checkpoint Buick, 60 miles away. From there, the platoon begins its movement to Khutaylah, 22 miles further north across harsh terrain, and only five miles from the Syrian border. This will be their forward operating base as they conduct both mounted and dismounted Distributed Operations in gaps between border forts along the Iraq/Syrian border that have allowed smuggling over the past years. Their mission is to conduct patrols along the border the Iraqi Border to prevent the movement of insurgents into Al Anbar from the Syrian frontier. They will be linking up with their sister platoon within the next 72-96 hours. Contact with enemy fighters is not expected, but always a possibility. Communications between the deployed platoon and both the company headquarters and MEU Headquarters will be maintained continuously.

0630 14 October, once the DO platoon occupies an abandoned building well outside Khutaylah, the platoon begins to improve its communications links with the company headquarters and MEU Headquarters. Utilizing the ETCS, (additionally, each squad will have in its complement, the PRC-117 UHF/VHF as primary or PRC-150 HF as secondary) the platoon radioman and the appointed radioman from each squad transmits back to both headquarters to indicate that they have established a operating base and beginning operations in zone. Through the platoon's EPLRS system, they will also update the Position Location Information (PLI) for each maneuver element and command element.

0700 14 October, after the DO platoon arrived in zone, they are advised that their frequency sets conflict with adjacent units along the border and that they must shift frequencies in order to avoid cross talk. The radio checks begin and are accomplished quickly thanks to the unit currently being largely co-located. The Platoon Commander (PC) confirms to company headquarters that he has solid communications via PRC-148 with each squad of the DO platoon. Below the squad level, radio checks are accomplished through the use of the Personal Role Radios (PRR) that each member is equipped with. PRR's enable short range communications between members and their frequencies tend to not affect the adjacent units in zone.

Due to the frontage that must be covered, and the scalability of theses units, the DO platoon reorganizes itself based on METT-T into two distinct teams. Team A, under the charge of the Platoon Commander (PC), will consist of two squad sized elements. Team B, under the command of the Platoon Sergeant (PS), will also consist of approximately two squad sized elements.

Once departed, Team B would consist of two squads which will operate autonomously away from the PC and under the command of the Platoon Sergeant (PS). The remaining two squads, Team A, will stay closer to the operating base under the control of the PC. Both Team A & B would remain well outside of supporting fires, meaning that they are basically reliant on the use of on call aviation assets. Each member is trained in call for fire and terminal control for close air support (CAS), but the DO platoon is not guaranteed those assets. Each maneuver element is equipped with a modified HMMWV called the Internally

Transportable Vehicles (ITV) from which they base their patrols. Radio communications equipment is kept in these vehicles until such time as the platoon goes foot-mobile. The PRC-117 and PRC-150 are typically rack mounted in the vehicle due to weight and power requirements but can be man-portable for limited duration.

The complement of radios and their primary role for each DO platoon is listed in Table 1.

	Nomenclature	Waveform	Range	Role
	Personal Role Radio (PRR)	UHF	500 – 1000 meters	Intra-Team Communications
	PRC 148	VHF / UHF	VHF: 4-7 mi UHF- LOS	Platoon - Squad - Team C2 CAS Control
	Expeditionary Tactical Communications System (ETCS)	Netted Satellite Communications (Low earth orbit)	Worldwide	Squad - HHQ Plat - HHQ Fires Request **PLI (OTH/OTM)**
	PRC 117	VHF / UHF / Satellite Communications	VHF:7-10 mi UHF: LOS Sat: WW	Squad - Plat - HHQ CAS/Fires Control **(OTH - Digital)**
	PRC 150	HF / HF Digital	30+ miles	Plat - HHQ **(OTH)** Logistics

Table 1. Communications Equipment and Capabilities[38]

[38] Marine Corps Warfighting Lab, ***DO 2006 Capabilities and Enhancements Report***, Jan 19, 2005, p.3.

The complete Table of Equipment (T/E) would be:
PRR:44 (Officer: 1, Corpsman: 1, Enlisted: 42)
PRC-148:11 (3 per squad and 1 per command group)
ETCS:5 (1 per squad and 1 per command group)
PRC-117: 5 (1 per squad and 1 per command group)
PRC-119: 5 (1 per squad and 1 per command group: alternative to PRC-117)
PRC-150: 1 (command group "A")

The overall platoon complement of radios is a combined total of 71 radio sets per platoon.

0800 14 October, after numerous attempts, successful radio checks and validation of PLI is accomplished and the unit begins its movement further west. The DO platoon's mission duration is estimated to be five days and they are expected to establish contact with local inhabitants and to develop a network of contacts in hopes of receiving additional information while the platoon is conducting operations.

2030 15 October, after 36 hours in zone, the two DO platoon's teams are dispersed and positioned along an extended frontage in order to observe as much battlespace as possible. At this time Team B observes two groups of armed men in pickup trucks moving towards the village of Khutaylah from the west. Additionally, the team reports their position has not been compromised and they will continue to observe from their observation position. The team reports this information to the PC via situation report (SITREP). Based on Rules of Engagement (ROE), the DO platoons have authority to engage suspected insurgents

based on the complement of weapons reported to the PC and as a result of the team's SITREP report, the PC initiates a call for CAS to engage the building where the two groups have take refuge.

2045 15 October, the PC submits request for CAS along the TACC using the ETCS. After mutual authentication, the request is forwarded to the TAOC, the DASC, and finally to the TACP. The underlying precept is "silence is consent" meaning the mission will proceed unless specifically denied. Al Asad airbase launches a section of AV-8B's to support the call and, 20 minutes later, the Harriers are overhead. Now, the PC switches to his PRC-117 to coordinate with the FAC(A) and direct the strike.

Once the 9-line is relayed to the section, the Harriers commence their run. A total of 50 minutes has passed since the initial call from the team. As final preparations for the strike are completed, the two teams of insurgents begin to move out of their location. The first truck speeds west towards Khutaylah and the platoon's operating base, while the second is delayed due to vehicular issues. While the insurgents are working to repair the vehicle, the first BLU-126/B hits the building and destroys the structure, damages the vehicle and the scatters the remaining insurgents.

2200 15 October, the section of Harriers receive a priority CAS mission from the DASC and immediately depart the sector to support a more critical mission. Since Team B has maintained observation of the insurgents through the use of NVG, the final task of destroying the target is tasked to the Marines of Team B, while the task of destroying the remaining vehicle falls to the PC and Team

A. The PS finalizes the coordination required to execute an assault on the remaining insurgents. Switching to his PRC-148, the PS verifies the receipt of his mission and acknowledges that PC and Team A will engage the escaping truck.

2215 15 October, the PS, alternating between his PRC-148 and PRR, directs the PC onto the rapidly moving vehicle while he finalizes the forthcoming assault on the remaining insurgents in the building. Based on traffic sent via PRC-148, the PC initializes a hasty ambush, and directs the 1st squad to set up on the far side of the road and engage when the truck is in sight. The 2nd squad is to stay on the near side and support 1st squad when the insurgents dismount.

Concurrent with the PC planning, the PS and Team B begin their assault on the remaining insurgents who have taken up a defensive position in a structure adjacent to the destroyed building. Team B, utilizing its 3rd squad as a support by fire position and its 4th squad as an assault unit, begins its attack on the insurgents held up in the smaller structure. The PS would travel with the assault element and ensure the lead trace reporting of the assaulting unit to the support by fire position. Unfortunately, as the 4th squad began its assualt, the PS PRR malfunctioned. There was ineffective reporting as a result of this malfunction, but the PS and the 4th squad leader were able to rely on the secondary lead trace signal which was based on IR flashes. Besides this malfunction, the Team B's assault was successful. The insurgents were killed and an enormous amount of intelligence was collected from the destroyed building, truck and from the neutralized insurgents.

Concurrent with Team B actions, Team A engages the vehicles and the insurgents which were heading toward Khutaylah. After being engaged, the insurgent come to a halt just west of the ambush site, immediately firing in the direction of 1st squad. Communication traffic over the PRC-148 is saturated and Marines have to rely upon training to work through the fog of war, but even with NVG's, it is difficult to discern good guys from bad. A team from 2nd squad identifies an opportunity to establish a support by fire position and dashes across the road to support 1st squad. However, 1st squad is unaware of 2nd squad's efforts and witnesses an unknown group of armed men moving across the road toward their location. 1st squad then reports that the unidentified men have begun firing on members of 2nd squad.

Not knowing where the incoming fire initiated, 1st squad takes cover in a ditch on the side of the road and after a short check of his squad reports no injuries. 1st squad leader calls the PC on their PRC-148 to report their situation. After a great deal of communication via the PRC-148's the two maneuver elements of Team A are able to identify each other and their locations. The teams are able to locate one another through the use of near and far recognition signals and eventually link up and coordinate their fight against the remaining insurgents, neutralizing them and moving in to collect intelligence.

0245 17 October, after a few hours of site exploitation and intelligence gathering, both Team A & B were able to back brief the PC in great enough detail to enable him to submit a finalized report to his company headquarters. After a great deal of SITREPs and updates,

the platoon was ordered to new observation positions and ordered to continue patrolling. Team A and the PC remained tied into the structure of the former border fort, while Team B pushed back out to an overwatch position well out of sight of the town and away from the previous compromised observation site.

2200 17 October, Team A is nearing completion of their patrol when it is tasked to conduct a physical link up with a DO platoon who would be patrolling to the northeast and adjacent for the forthcoming days. Mission orders released prior to crossing the Line of Departure (LOD) indicate the frequencies the second platoon can be contacted on, but as a result of the communication complications earlier in the operation the PC is required to first utilize the ETCS to establish contact and pass the adjusted frequencies and coordinates.

Unfortunately, the second DO platoon has had problems with their ETCS and is unable to be contacted; instead they utilize the PRC-150 to communicate with their company headquarters in an attempt to relay to first platoon their communications situation. After more than 60 minutes with no success and finally receiving updated intelligence from the MEU headquarters about the frequency issues from earlier in the patrol. At this time the second DO platoon switches back to the PRC-117, and with the updated frequencies tries again to reach the first DO platoon. After 15 more minutes, the platoons successfully contact one another and establish a rendezvous site and time.

Conclusion: The scenario given above highlights the limitations faced by DO platoons conducting operations. With 71 radio sets, the Marines are encumbered with nearly

twice as many units as needed. Having to continually switch radio sets to communicate within the platoon has the potential to breed confusion. A 44 man platoon needs 44 radios that work in unison. Additionally, it is clear to the authors that the training, initiative and skills of a DO company and various DO platoons would often time prevent such freshman errors (i.e. inaccurate communication, frequencies, movement without coordination, or redundant communication during the assault) from occurring at all, but attention to these potential errors needs to be identified as concerns which must be addressed for future combat operations.

G. NEED FOR CHANGE

In order for the Marine Corps to accomplish this long range vision, the flow of information in lateral and vertical pipes must be unparalleled in history. Unfortunately, this means better communications. Better communications means better radios. **The authors assert that until the USMC identifies and equips its DO units with emerging technological assets that can provide an integrated system for communicating, reporting, and friendly force identification and are functional within the NCW concept, the Marine Corps will continue to fall short of the intended goal**.

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III. MESH NETWORKS AND DISTRIBUTED OPERATIONS

A. INTRODUCING A WIRELESS SOLUTION

The proposed DO organization, as depicted in Figure 7, gives a snapshot of the platoon as conceived by the Marine Corps Warfighting Laboratory (MCWL) and is representative of the generic model utilized by the authors in demonstrating the "as-is" and "to-be" transition of legacy and new communication technologies.

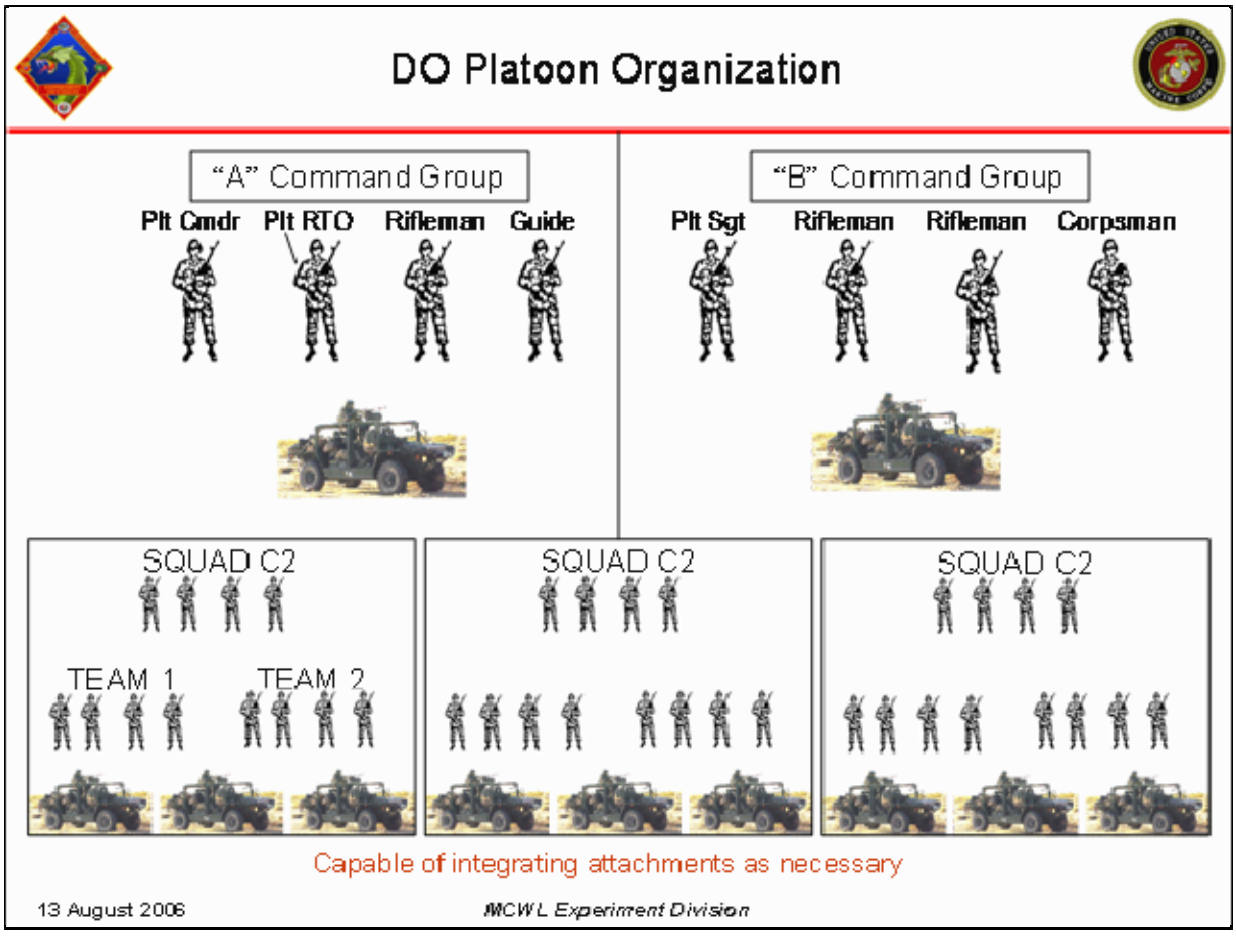

Figure 7. DO Platoon Structure[39]

[39] Marine Corps Warfighting Lab, ***DO 2006 Capabilities and Enhancements Report***, Jan 19, 2005, p.2.

Figure 8 presents the MCWL concept of how the DO platoons and squads will communicate with one another. Utilizing the concept of mesh, each squad acts as a representative node within the mesh construct able to communicate with adjacent nodes/squads, ultimately able to communicate with platoon headquarters. This framework can be abstracted up to company, battalion, regiment, and even division headquarters with each Major Subordinate Command (MSC) being a node within the mesh architecture.

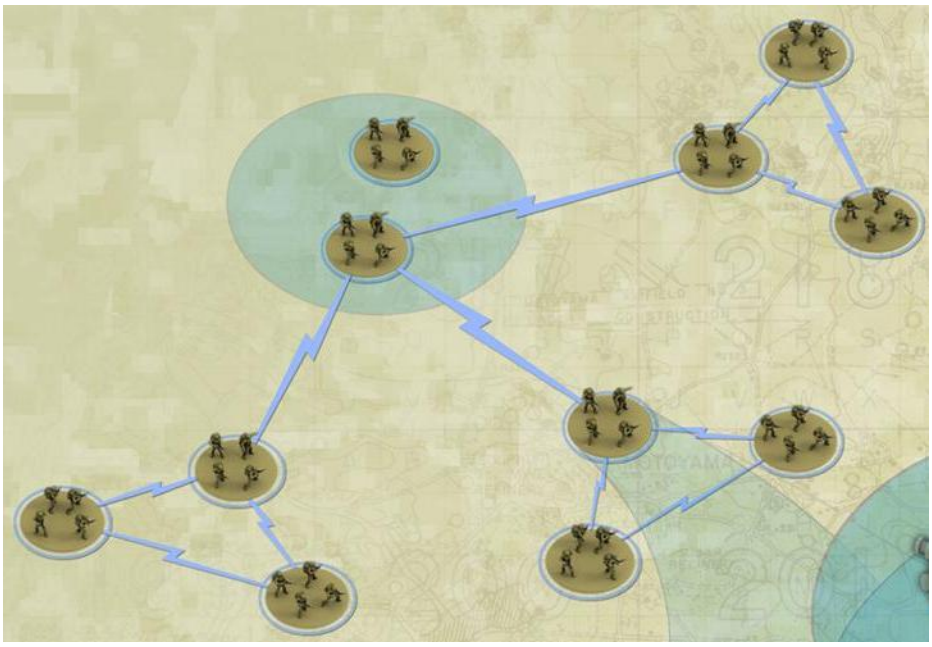

Figure 8. DO Communications Abstract[40]

At issue, and the primary purpose for this thesis, is to explore the feasibility of fielding communications devices to DO units that provide reachback to higher headquarters and ultimately the GIG; devices that enable a

[40] Marine Corps Warfighting Lab, ***DO 2006 Capabilities and Enhancements Report***, Jan 19, 2005, p.2.

range of functions ranging from basic voice communications, to text messaging, file sharing, and video feeds, as well as other crucial applications that enable the warfighter to see the battlefield as never before.

The communications architecture for DO platoons consists of COTS and Government of the Shelf (GOTS) radio sets that were previously only available to battalion and regimental units. The current radio sets are listed in Chapter II and will not be re-enumerated, however, Figure 9 will provide a visual to enhance the concept.

Figure 9 provides a high-level view of the multi-asset approach needed to communicate at the various levels, from the MEU to the platoon, from the command group to the squads, and from the squad leader to the fire teams.

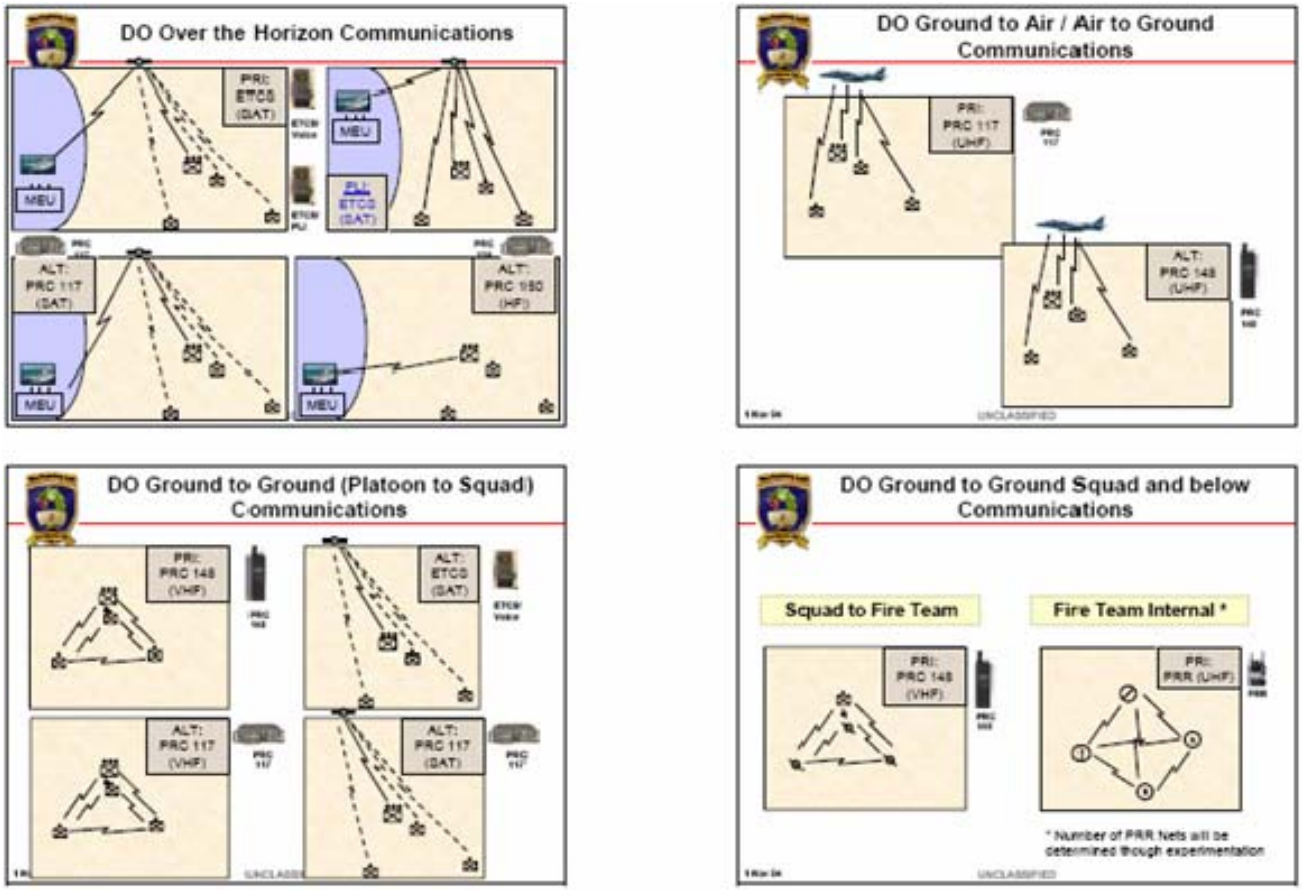
DO Over the Horizon Communications
DO Ground to Air / Air to Ground Communications
DO Ground to Ground (Platoon to Squad) Communications
DO Ground to Ground Squad and below Communications
Squad to Fire Team
Fire Team Internal *
* Number of PRR Nets will be determined though experimentation

Figure 9. DO Communications Architecture[41]

The Figures 10 and 11 display the distribution of communications assets within the platoon, down to the fire teams.(Next page)

[41] Marine Corps Warfighting Lab, ***DO 2006 Capabilities and Enhancements Report***, Jan 19, 2005, p.4.

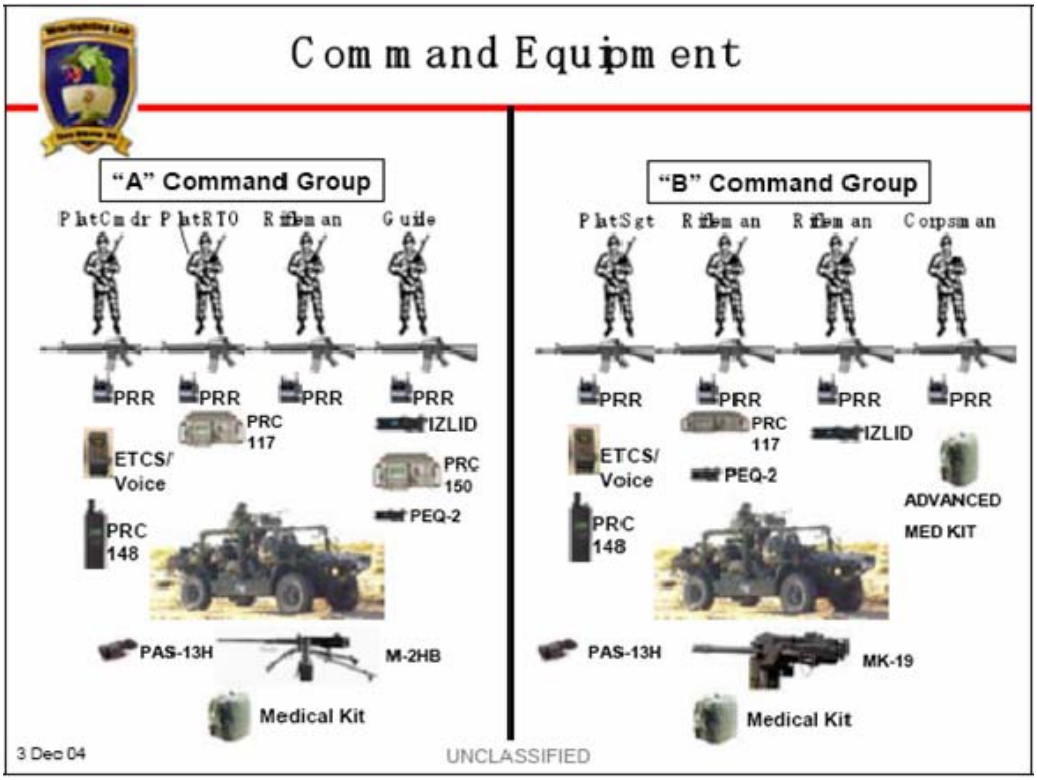

Figure 10. Command Communications Distribution[42]

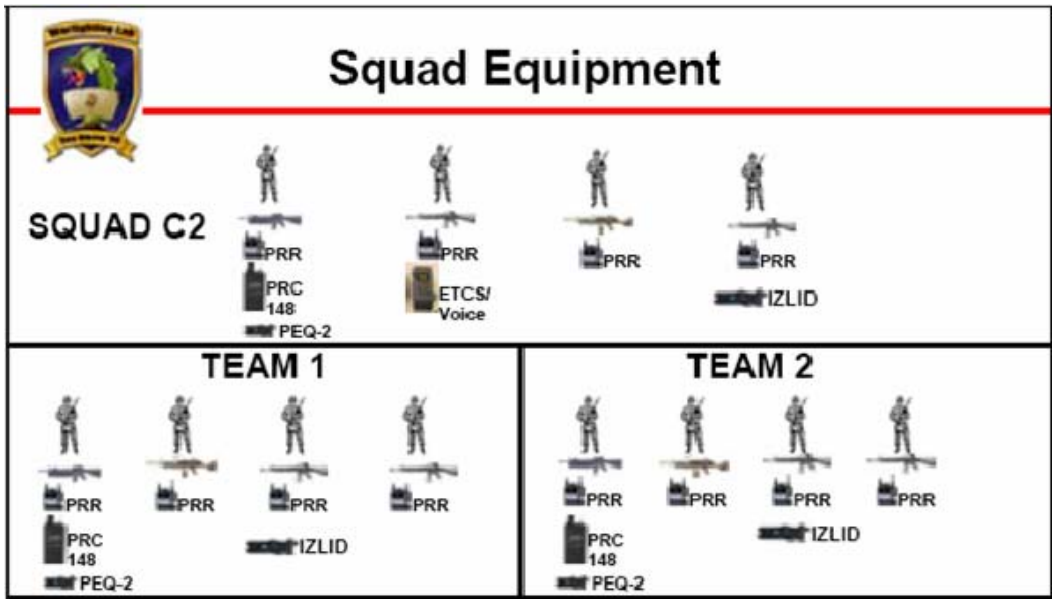

Figure 11. Squad Communications Distribution[43]

[42] Marine Corps Warfighting Lab, ***DO 2006 Capabilities and Enhancements Report***, Jan 19, 2005, p.2.

B. REORGANIZATION OF COMMUNICATION FLOW

Figure 12 provides a schematic of how a reorganized communications suite would potentially be constructed with the new communications paradigm for DO platoons. The casual observer would notice that it follows the traditional command structure as far as bridging from one subnet to the next, the differences will be made clear in Chapter IV when the authors propose how to establish a preliminary architecture for this innovative unit. The authors introduce this decomposition here to simply illuminate the salient differences between the current methodology and their vision for the future communications architecture, yet to be built.

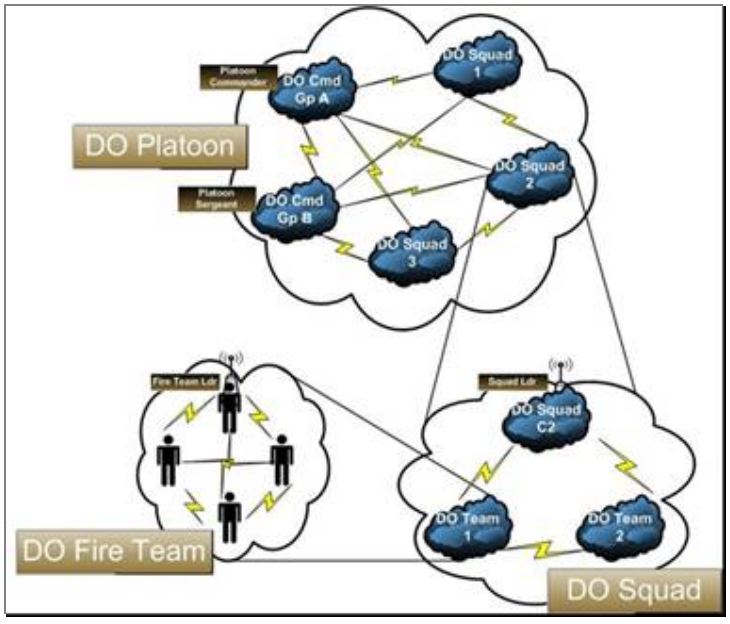

Figure 12. Proposed DO Communications Architecture

[43] Marine Corps Warfighting Lab, ***DO 2006 Capabilities and Enhancements Report***, Jan 19, 2005, p.3.

C. WIRELESS MESH DEFINED

A mesh network is an extension of the traditional wireless network (Figure 13) which typically consists of a router that is physically connected to a larger network or the internet, and a Wireless Access Point (WAP) that in turn communicates to several devices. This configuration is also termed the Basic Service Set (BSS). The limitation of the BSS is that the WAP has a limited range, typically 100 meters (802.11 protocol) and can handle a maximum load of 30 users at any one time (802.11 protocol)[44].

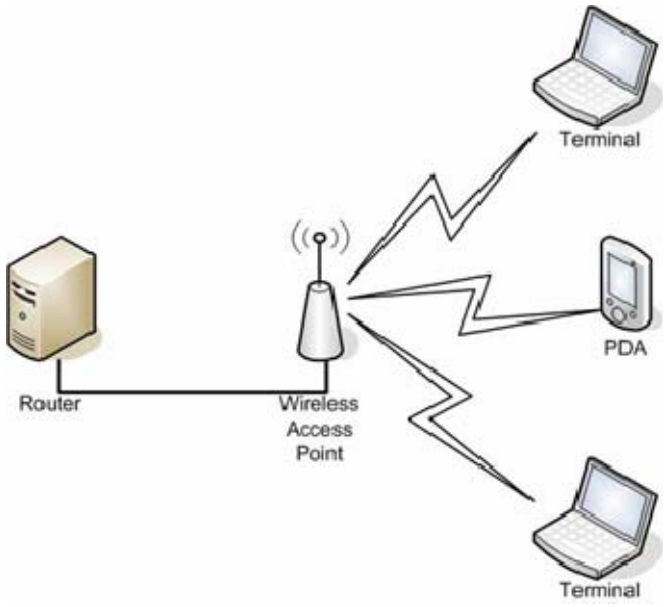

Figure 13. Basic Service Set

Building upon the BSS is the Extended Service Set (ESS) which is a set of two or more interconnected BSSs and integrated local area networks (LANs) that appear as a single BSS to the user (Figure 14). This configuration allows the user to be relatively mobile; once association

[44] INTEL Corp., ***Understanding Wi-Fi and WiMax as metro access solutions***, WiFi and WiMAX Solutions, (INTEL Corp: San Jose, 2004), p.7.

to the network is established, a user may freely roam between WAPs and still remain connected to the network unless he moves outside of the range of any WAP on the LAN.

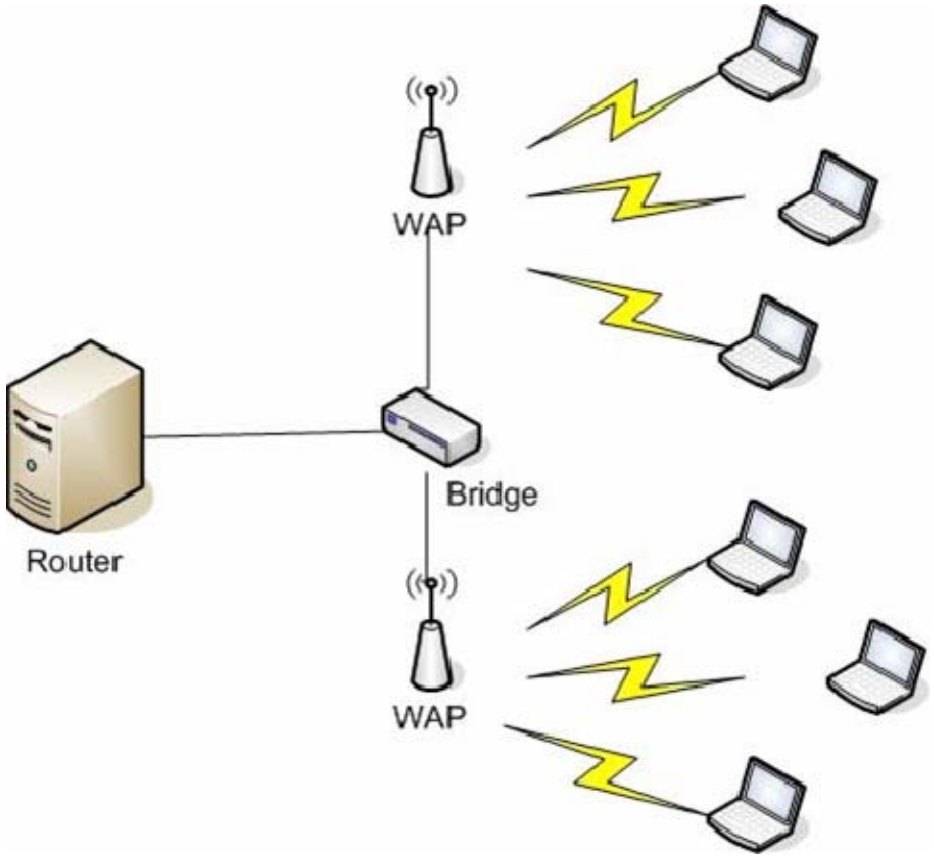

Figure 14. Extended Service Set

In contrast to the traditional configuration, a Wireless Mesh Network (WMN) is a network of independent nodes that function as routers, sending and receiving messages, and relaying messages to its neighbors. The relaying characteristic enables each node to provide a multi-hop routing capability which introduces a possible solution to the larger mobility issue (Figure 15).

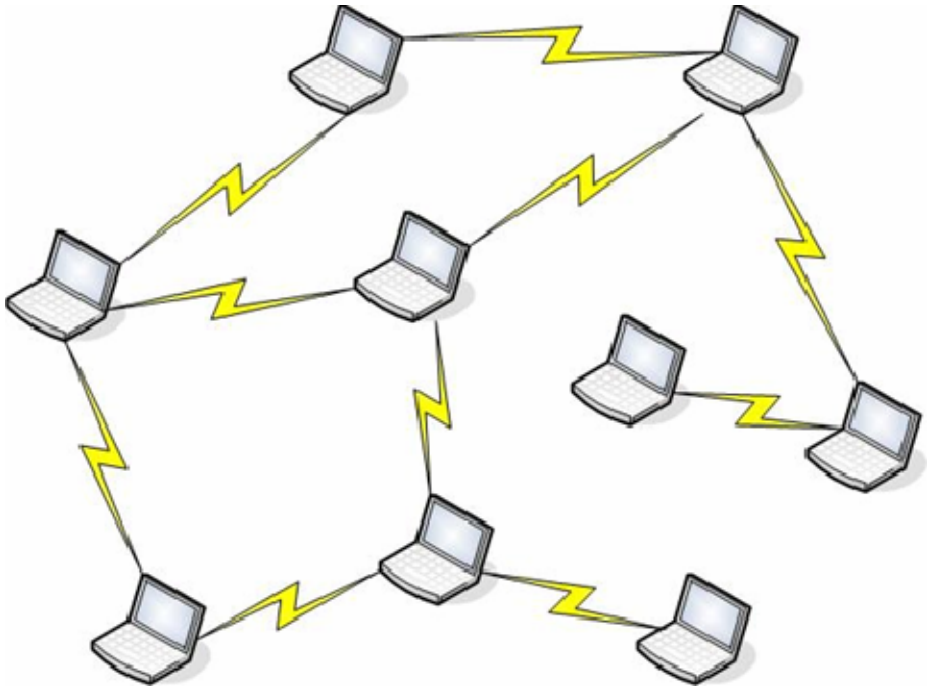

Figure 15. Basic Mesh Network

D. PROS AND CONS OF WIRELESS MESH

This configuration would appear to be the answer to a tactical scenario, and it is, until the limited range of the wireless network cards (typically PCMCIA or integrated)is factored, as well as the limitations of 802.11 type cards that have difficulty transmitting through buildings, trees, hills, vehicles, or other such obstructions typically found in a combat environment. The authors will discuss the benefits and drawbacks of the wireless mesh network as well as some of the difficulties faced in trying to adapt the various technologies to a tactical environment.

1. Benefits of 802.11 and 802.16 Technologies in a Mesh Network

a. Self-forming

Nodes within a mesh network have the inherent capability of discovering neighboring nodes in a couple of ways depending upon the algorithm contained within their software, they can either continuously query for new nodes, or wait for a new node to request association on-demand.

b. Physically Extends Traditional Networks

By virtue of having an integrated wireless card, or inserting a PCMCIA card into a slot, a laptop or PDA is free to roam within the range of the mesh network, establishing a new connection with its closest neighbor. This is done transparently to the user.

c. Peer-to-Peer Routing

The ability of each node to route traffic and share information is different than client-server configuration and what makes up the architecture of the internet. Routers share information as well as routing tables that keep the topology of the internet healthy and greatly enhance the survivability of the net. This redundancy is one of the greatest strengths of a mesh network by increasing the overall availability of the network and giving it the ability to self-heal. Were a node to drop off of the net, or a link between nodes was no longer viable, the surrounding nodes would be able to detect this and compensate accordingly.

d. Availability

802.11 technology is ubiquitous and inexpensive. Practically every modern household within the United States has at least one router and WAP. This makes the idea of constructing ad-hoc tactical networks with 802.11 technologies very attractive. 802.16 technologies are emerging but are still in their infancy, the authors predict their availability to increase with a corresponding decrease in price.

2. Drawbacks to an 802.11 Mesh Network

a. Range

Current 802.11 technology is limited by FCC regulation to transmit at a power setting that restricts its maximum effective range to approximately 100 meters, less when factoring in obstructions. This attempts to prevent the device from affecting, or being affected by, other 802.11 devices. This limitation inhibits any tactical usage.

b. Security

802.11 wireless cards are omni-directional, increasing both the probability of detection as well as the probability of intercept (POD/POI). Further, the security protocols established for 802.11 (WPA and WEP) have known vulnerabilities[45] that compromise their integrity and effectiveness on the battlefield.

[45] Joel Snyder and Rodney Thayer, "WPA – An accident waiting to happen," Oct 4, 2004, <http://www.networkworld.com/reviews/2004/1004wirelesswpa.html> (last accessed Aug 28, 2007) and L. Padilla, "Active WEP Cracking," http://www.gae.ucm.es/~padilla/extrawork/activewepcrack.html (last accessed Aug 28, 2007)

c. Saturation

Wireless technologies have a limit as to how many subscribers can be accommodated at any given time. This is due to having to provide equitable service to all but only so much time with which to do so. 802.11 subscribers compete for access to the WAP every time they communicate using CSMA to 'hear' other users. In an outdoor setting, this limits your useable subscribers to 10.[46]

d. Conclusion

The authors do not wish to tie a specific technology to any proposed solution, instead allowing an open architecture approach to solving a constantly moving problem. The authors research, however, has lead us to focusing on 802.16 as a viable option to many of the problems addressed above. Although 802.16 devices would utilize omni-directional transceivers, their security aspect greatly reduces the probability of exploitation[47]. The primary benefit of 802.16 is range. Though intended for static solutions, 802.16 is increasingly becoming popular for mobile users[48].

E. DISTRIBUTED OPERATION UNIT ASSUMPTIONS

The following comprise the salient issues when dealing with DO units and provide boundaries with which to limit the scope of The authors research and allows that research

[46] PROXIM Corp., ***Wireless Outdoor Routing Protocol***, Technology Overview, (San Jose: Proxim Corp., 2003), p.2.

[47] Rex Buddenburg, "802.16 WAN Security Issues", unknown, <http://roland.grc.nasa.gov/~ivancic/RFI/responses/NavalPostgraduateSchool.txt> (last accessed Sep 17, 2007).

[48] "What is WIMAX?" <http://www.palowireless.com/i802_16/wimax.asp> (last accessed Sep 17, 2007).

to assist in the functional development of a practical solution to support the warfighter.

1. Constraints[49]

- The DO unit is built around the Marine Corps four man fire team.
- Each DO team of 4 is mechanized, specifically, they operate a vehicle that contains a transmitter/receiver unit and router that provides for mobility across rugged terrain. Each vehicle maintains the capability of reachback to the MEU TOC as well as to other homogenous teams. (MCWFL has expressed that mounted operations are one capability and that solutions should not be vehicle-centric. To this end, all solutions are rack-mountable, which is preferable, as well as man-portable).
- DO units operate outside of the coverage of organic fires, with the exception of air.
- Maximum organic DO unit size is Platoon (1 Officer, 1 Corpsman, and 42 Enlisted).
- DO units do not intentionally conduct large urban operations, which is typically the job of the Battalion or Regiment.
- Members will be operating in close proximity to one another (<100m).
- Maximum operational time is 14 days.

[49] Marine Corps Warfighting Lab, ***Questions and Answers About Distributed Operations***, Mar 16, 2005.

2. Requirements

- Availability of 99.9889%[50] (intra-platoon)
- VOIP
- GPS reporting
- Nodal and/or orphan[51] discovery
- Medical emergency reporting

3. Expected Capabilities

- Voice
- Constant connectivity among Marines in the unit
- Map with GPS reporting
- File sharing
- Photo/Video
- Routing of messages (Multicast, Broadcast)
- Self-healing
- Self-organizing (based on pre-established criteria)
- Nodal/Orphan discovery
- Expandable/Upgradable

F. END-STATE: NETWORK-CENTRIC WARFARE

In addition to the need for all services to become interoperable and visible within the commander's

[50] Naval Postgraduate School, Feb 12, 2007, lecture, <http://web1.nps.navy.mil/~budden/lecture.notes/availability.html>, (last accessed Aug 28, 2007).

[51] The term 'orphan' refers to a member separated from his original group.

operational picture (Figure 16), there is also a need for the armed services to transition the manner in which they will wage combat against non-nation states and an asymmetric enemy. The concept of transformations of the armed forces was initiated to further the development of friendly armed forces' ability to sustain preeminence against emerging non-state threats and an asymmetric enemy. The manner in which the armed forces fight the nation's battles, as well as in the way C2 is maintained during those battles has been identified as a priority by the President of the United States (POTUS), the Secretary of Defense (SECDEF) and the Commandant of the Marine Corps (CMC).

Figure 16. Network-centric Warfare Vision[52]

The Marine Corps, for its part, has identified numerous areas in which it intends to interlink its future concepts under the required joint operability. In

[52] Sagem Défense Sécurité, "Optronics Systems & Optics : Global solutions", Network Centric Warfare/BOA, <http://www.sagem-ds.com/eng/site.php?spage=02020603>, (last accessed Aug 30, 2007).

accordance with Joint Vision 2020 (JV2020) it has been conducting aggressive experimentation with Ship To Objective Maneuver (STOM), Operational Maneuver from the Sea (OMFTS), and DO to name a few (Figure 17).

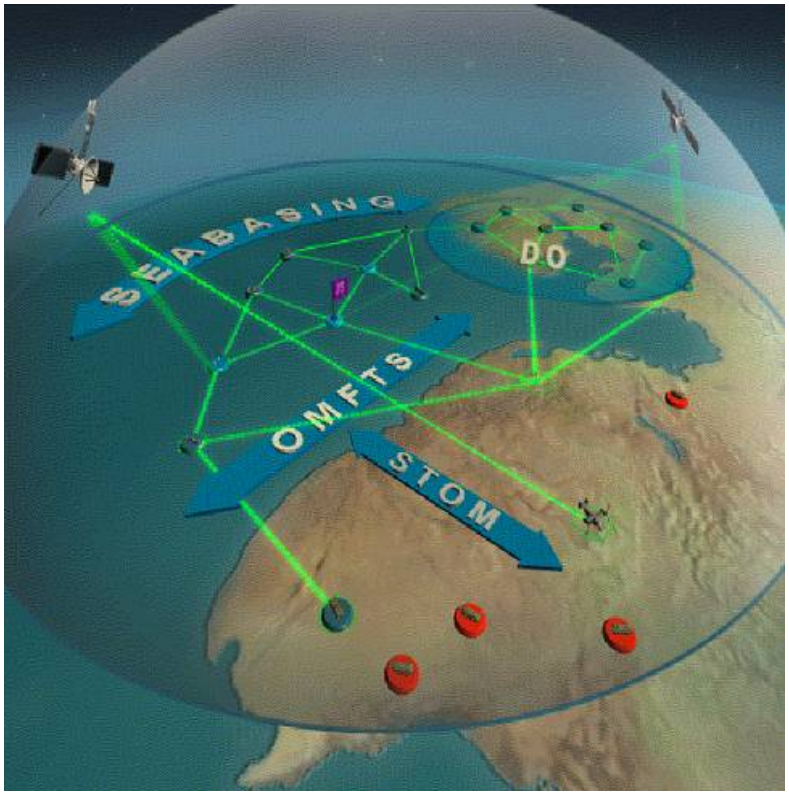

Figure 17. The USMC concepts and NCW[53]

As described above, the DoD's long-term vision is to enable constant communications with the emerging GIG. The Marine Corps, for their part, needs to come into alignment with Joint Vision 2020 by transforming their communications architectures to seamlessly integrate the individual Marine into the overarching concept that is the joint force of the modern battlespace.

[53] Marine Corps Warfighting Lab, ***DO 2006 Capabilities and Enhancements Report***, Jan 19, 2005, p.3.

G. CONCLUSION

By definition, NCW is an "information superiority-enabled concept of operations that generates increased combat power by networking sensors, decision makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability, and a degree of self synchronization. In essence, NCW translates information superiority into combat power by effectively linking knowledgeable entities in the battlespace."[54]

[54] D.S. Alberts, J.J. Garstka, and F.P. Stein, ***Network Centric Warfare: Developing and Leveraging Information Superiority***, Department of Defense's Command and Control Research Program, October 2003.

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IV. ANALYSIS AND RESULTS

A. TACTICAL NETWORK TOPOLOGY

In this section, the authors will demonstrate the COTS devices currently being fielded to small combat units by private industry that is attempting to build an architecture around their products. The fundamental flaw with this approach is that they are building the system backwards. Instead of working from a defined DoD communications architecture and implementing products that support it, these companies have identified an implicit requirement and have begun to construct a system to fit that need.

Numerous devices have been rigorously tested in experimentation that has spanned years of combined testing both in laboratories aboard Naval Post-graduate School as well as aboard Camp Roberts Army National Guard Base, near Paso Robles, CA, during the quarterly NPS-USSOCOM cooperative field experiment program. These experiments provide a proving ground for testing of mobile communications devices, software applications to improve situational awareness (SA) on the battlefield, and remote sensors such as unmanned aerial vehicles (UAV).

B. AVAILABLE EQUIPMENT

The Inter-4 Tacticomp adaptable line of products are Wireless, VOIP, and GPS enabled computers that have been ruggedized for field use. The Tacticomp products offer a unique level of integration within a lightweight, adaptable and rugged design.

These devices, manufactured by Sierra Nevada Corporation (SNC), have received a great deal of attention and with good reason. These devices are currently being fielded with numerous Army units from the small elite Ranger Regiments to the new Stryker Brigades. The Tacticomp 5 & 6 (Figures 13 & 14) are the larger and more capable of the devices. These particular computers tend to be vehicular mounted, but are capable for dismounted operation. The Tacticomp 1.5 (Figure 15) is equally as rugged piece of equipment. This reinforced PDA serves as a reliable and lightweight unit that can be carried by each dismounted Marine or soldier in a unit.

As with most emerging technologies, there are a few drawbacks. The shortfalls of this particular product line are not the focus of this thesis. On the contrary, the authors identify this system purely to represent the availability of capable products within the COTS and GOTS procurement system. Without question, the shortfalls of these devices would need extensive discussion to a level that exceeds this thesis.

First and foremost is the lack of interconnectivity. All SNC devices can only interconnect with other (non-SNC) devices only through the use of an external tactical radio set. Secondly, these devices are currently only 802.11 compliant. Modifications would have to be made to become 802.16 compliant, the authors and numerous NPS Staff and Students have discussed this issue with SNC. Lastly, the Tacticomp's have proven unable to handle excessive amounts of traffic; specifically with regards to video.[55] The

[55] TNT experiment August 2006

specifics are that each device was operating at or near capacity with regards to applications (chat, video, and voice communications) and the 400 MHz processor was unable to accommodate such a heavy work load, the authors will address this issue as a matter of proposed architecture.

Figure 18. INTER-4 Tacticomp 6[56]

Figure 19. INTER-4 Tacticomp 5[57]

[56] SNC Corp., ***INTER-4 Tacticomp Radio 6***, <http://www.sncorp.com/prod/c4n/int4/tacticomp1.shtml> 2006, (last accessed Aug 30, 2007).

[57] SNC Corp., ***INTER-4 Tacticomp Radio 5***, <http://www.sncorp.com/prod/c4n/int4/tacticomp1.shtml> 2006, (last accessed Aug 30, 2007).

Figure 20. INTER-4 Tacticomp 1.5[58]

2. INTER-4 Micro Mesh Router (MMR)

This specific Tacticomp device is utilized as an omni-directional wireless router for separate mesh groups to communicate at data rates of 2 Mbps up to 12 miles. Though billed as a router, the device actually works as a bridge, it does not perform layer 3 routing. The MMR is suitable for mounting on vehicles as well as man-portable. The practicality of the MMR is in its ability to link meshed groups.

[58] SNC Corp., ***INTER-4 Tacticomp Radio 1.5***, <http://www.sncorp.com/prod/c4n/int4/tacticomp1.shtml> 2006, (last accessed Aug 30, 2007).

Figure 21. INTER-4 MRR[59]

C. C2 APPLICATIONS

1. Command and Control Personal Computer (C2PC)

A Windows-based application designed for MAGTF tactical data systems, interoperable with the Global Command and Control System (GCCS) already in use with the DoD.

2. Command and Control Compact Edition (C2CE)

A newer application designed for pocket PC's that emulates C2PC when used by the D-DACT.

Both of these applications are intended for the warfighter to have the ability to have mapping, GPS, common operational picture of the battlespace, a digital workspace to replace paper map boards and the various overlays used on them. Either application is suitable for use in the

[59] SNC Corp. *INTER-4 Omni-directional Micro Mesh Router*, <http://www.sncorp.com/prod/c4n/int4/odmmr.shtml> 2006, (last accessed Aug 30, 2007).

proposed architecture and is only intended to give examples of software applications that can handle the requirements of the DO unit.

Some of the functionality required by DO units that these applications provide are Graphical Overlays such as Intel, COA's, Friendly and Enemy Situational Awareness. They will also have the capability of Reporting, Messaging, and Mapping, and numerous other infantry related functions.

D. ROUTING PROTOCOLS

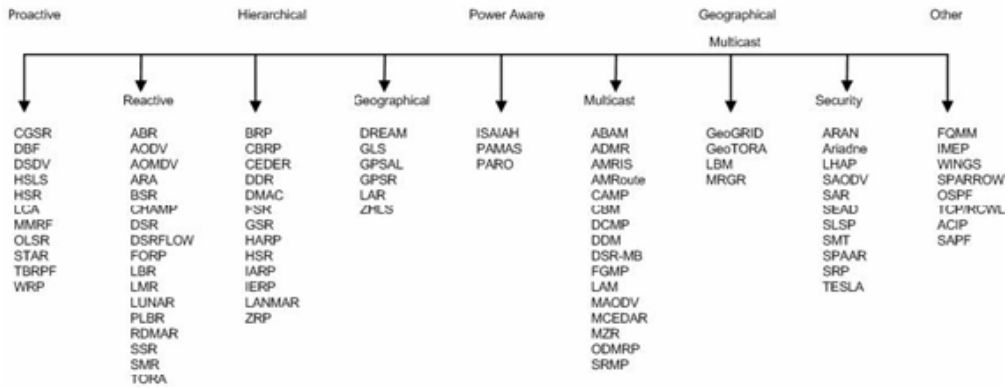

Table 2. Routing Protocols[60]

The greatest flexibility of mesh networks in any environment is routing. Divided into 3 major philosophies, routing protocols are the heart and soul of the Mobile Ad-Hoc Network (MANET) and there are myriad proposals as to the best solution (see Table 2 above). Each has strengths and weaknesses. The most appropriate ones are listed below, after a brief description of the routing philosophies.

[60] Mattias Halvardsson and Patrik Lindbert, ***Reliable Group Communication in a Military Mobile Ad Hoc Network,*** Master's Thesis, Vaxjo University, Feb 2004.

1. Proactive MANET Protocols

Proactive protocols such as OLSR and DSDV are table-driven and use stored values to maintain a record of nodes within the network. This reduces latency of data delivery since the route is stored and available when required, the down side is that a great deal of overhead is required to maintain the routing tables that make up the network.

2. Reactive MANET Protocols

Reactive protocols such as AODV and TORA determine routes between nodes on demand, meaning that the delivery route is determined when a node has information to deliver. This philosophy reduces the amount of communication overhead that is required of a table-centric proactive method, but can lead to possible delays between route request and transmission as the optimal route is determined.

3. Hybrid MANET Protocols

The last major division of routing protocols attempts to capture the most attractive aspects of the first two while simultaneously avoiding the detractors. Among these hybrid protocols are proposals such as Zone Routing Protocol (ZRP) which segments the network into zones and proactively establishes tables within a specific region to determine the best possible route for delivery. This protocol was proposed to the MANET working group but was not adopted[61].

[61] "Zone Routing Protocol", Wikipedia <http://en.wikipedia.org/wiki/Zone_Routing_Protocol>

An additional protocol that seems more suitable to the tactical environment is Open Shortest Path First (OSPF). This method is the most widely used Interior Gateway Protocol (IGP) for large networks and uses Dijkstra's Algorithm to determine the shortest path tree with path cost as its routing metric. Path cost is determined by the speed (bandwidth) of the interface addressing the given route[62].

Protocols have been devised with the mobile user specifically in mind. Of these, Optimized Link State Routing (OLSR) and Ad-hoc On-demand Distance Vector (AODV) are pre-eminent. OLSR being proactive and AODV being reactive, they both provide contrasting benefits to the network. OLSR is the fastest in establishing connections, but is continuously discovering the network, meaning that it is constantly communicating with the network to keep its routing table updated, incurring a good deal of overhead. AODV, by comparison, is simpler, requires much less overhead, less memory, and fewer calculations, but suffers from greater delay. Additionally, a corresponding increase in communication is incurred when a new route is needed[63].

Routing protocols have a fundamental set of requirements that are listed below. These requirements dovetail into the requirements for mesh networks and have been the foundations for MANET.

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[62] "OSPF Working Group" IETF <http://www.ietf.org/html.charters/ospf-charter.html> (date last accessed Aug 30, 2007).

[63] Dr. Don Moskaluk, "Wireless Mesh Topology", <http://www.moskaluk.com/Mesh/wireless_mesh_topology.htm> Jan 2004 (last accessed Aug 30, 2007).

- Self starting and self organizing
- Multi-hop, loop-free paths
- Dynamic topology maintenance
- Rapid convergence
- Minimal network traffic overhead
- Scalable to "large" networks[64]

The authors have surveyed two leading protocols for analysis in this thesis, one each from either end of the routing spectrum. OLSR comes from the pro-active camp, and OSPF which is a re-active routing protocol. The authors envision a hybrid of both but in different subnets; for inter-fire team), the OLSR protocol offers the better choice. Fire teams are well-defined in area and as such, are well suited for a pro-active routing protocol. Conversely, squads (and the platoon as a system) are far more diverse in area and would be better suited to a reactive routing protocol. Fire teams, being fewer in number, can afford the overhead that a pro-active protocol brings with it. Squads (and the platoon as a system) would bog down the network with the overhead of a pro-active protocol and thus need a reactive protocol. However, the authors believe it should ultimately be up to the industry to devise suitable protocols to fit any final solution.

E. BENEFITS OF NCW TO THE WARFIGHTER

The Joint Chiefs of Staff published their vision of the Network-Centric Operational Environment (NCOE),

[64] Andreas Tønnesen, "Implementing and extending the Optimized Link State Routing Protocol", *OLSR.org,* <http://www.olsr.org/docs/master-pres.pdf> 2004, (last accessed Aug 30, 2007).

outlining what they call "Full Spectrum Dominance". [65] By adopting an architecture utilizing IP radios, the following benefits to the warfighter can be achieved, thereby bringing the Marine Corps into full compliance with the vision of the Joint Chiefs of Staff.

• ***Efficiency***—increased in terms of time, economy of force, and cognitive learning. Time efficiency is increased because ubiquitous network connectivity and good IM will reduce or eliminate the need to manually convert data and information. Also, automated machine-to-machine information sharing, and data translation through data services, will allow humans to concentrate on less mundane tasks. To optimize economy of force, every JTF element can call upon the capabilities of other JTF elements as appropriate. For quicker cognitive learning, KM and I-IM tools will enable each user to receive and focus on whatever information is needed, in a format tailored to best fit his/her professional and personal preferences.

• ***Cross Functional Synergy***—achieved by networking and synthesizing the Joint Force's data, including the traditionally separate staff functions of personnel (1), intelligence (2), operations (3), logistics (4), and military civil/ international affairs (5). These cross-connections can be leveraged to reveal new insights. For example, in preparing for an aerial strike mission, the NCOE will anticipate and retrieve essential planning information from known and trusted sources, augmented by event-driven alternate inputs. It will also provide

[65] Joint Chiefs of Staff, ***Net-Centric Operating Environment - Joint Integrating Concept***, Oct 31, 2005, pp.35-36.

warnings of in-process threats to the operation, followed by near real-time bomb damage assessments.

• ***Joint Cohesion***—enhanced by promoting technical connectivity and IM, while KM and NM tools will spread and improve ever-developing knowledge of how best to conduct cohesive Joint Net-Centric Operations Environment (JNCOE). The NCOE will link every Joint Force element to help find, disseminate, and implement "lessons learned" throughout the Force, continuously. It will also leverage various Joint Force capabilities heretofore latent. Called constructive interdependence, this depends upon a high degree of mutual trust as the Force's diverse members make unique contributions toward common objectives and rely upon each other for various essential capabilities instead of duplicating those capabilities organically (i.e., economy of force). The NCOE will achieve this by employing intelligent agents to search inventory databases and match requirements to individual unit capabilities. The NCOE will thus facilitate an almost limitless combination of Service and component capabilities in ways not previously achievable.

• ***Collaboration with Mission Partners***. Constructive interdependence is not limited to the Joint Force alone. The NCOE-enabled integration of mission partners via their networks will enable the JTF to share mission objectives, synchronize the operation, task-organize it for optimal efficiency, and enhance its effectiveness.

• ***Decision Superiority***—facilitated by providing every decision-maker with access to a wealth of relevant information and knowledge, including the very latest ISR

reports, the current operational picture, and the insights and advice of SMEs and/or COIs. Advanced visualization techniques will show unprecedented quantities of information, individually tailored to specific needs. Although the proverbial "fog and friction" of war can never be eliminated entirely, KM and I-IM tools will reduce its uncertainties and risks by promoting a higher level of situational awareness, further enhanced by applied analytical confidence factors, embedded modeling and simulation algorithms, and expanded knowledge sharing opportunities. Confidence weightings will be determined by a group of automated smart tools and programs designed to correlate data from various sources into a coherent information object.

Rapid Adaptability at the Tactical, Operational and Strategic levels—facilitated by the NCOE's comprehensive reach throughout the Joint Force and mission partners, enabling the near instantaneous dissemination of information, knowledge, and command guidance. Commanders at multiple levels can "drill down" to see any aspect of the tactical or operational picture they desire. Vital "lessons learned" will be acquired rapidly, improving the JTF knowledge-base and ensuring that the Force becomes better prepared to address recurring situations. If any Force elements require additional training or re-training to more effectively counter an adversary's asymmetric ways, various instructional aids will accelerate that needed training, such as audio-visual briefings, virtual reality simulators, and interactive software programs. Such training will be especially valuable for personnel who must perform

unexpected missions, such as artillery personnel compelled to perform counter-insurgency and military police missions.

F. MATERIAL BENEFITS

The following list of material benefits is not intended to be all encompassing, simply some of the more apparent functional items that current IP devices bring to the table.

1. Voice

Clear (No static).

VOIP has emerged as an exceptionally reliable and ubiquitous service, even over Wireless Internet Service Providers (WISP). Such providers as Vonage, Fonality, and others, are providing high quality service that rivals the Plain Old Telephone System (POTS).

2. Directional Communications

Mono Cast (1 Recipient)

Multi Cast (Sub net: Squad or Team)

Broad Cast (Entire Platoon)

As pointed out earlier in this thesis, push-to-talk radio systems are broadcast only, they cannot be directed to any one individual or sub-group within the larger group. IP radios provide an inherent capability to route packets to specific receivers or sub-groups.

3. Scalable Communications Architecture

Capability Sets

With limited bandwidth available to any tactical user, the concept of permissions becomes apparent when faced with

the necessities of combat. The rifleman from 1st fireteam does not need to same capabilities as the Squad Leader, who needs fewer than the Platoon Sergeant, and the Platoon Commander.

The author's have devised a permissions schema that addresses this and will be discussed below.

4. Data

Files (overlays, orders, data)

Imagery

Bio-metrics (friend or foe)

This is truly where the IP-based system comes into its own. File transfer and the ability to store and retrieve information provides tremendous benefit in the Network-centric realm of the 21st century battlefield.

5. GPS

PLI

Assists with the deconfliction of fires

Unambiguous

One of the most difficult aspects of battle is knowing where friendly and enemy forces are at any given time. The DoD has made numerous attempts to reduce the fog of war by introducing such initiatives as Blue Force Tracker and EPLRS, all of which are complicated and require specialized equipment to operate. GPS provides a much more accurate location and the receivers are incorporated in some of the most modern IP devices.

6. Reporting

Automated Reports

Logistical/Administrative Reporting

9 LINES (Close Air Support)

Call For Fire (Artillery)

CASEVAC

Having the ability to automate resupply of equipment reduces the amount of time and effort the platoon must place other than conducting combat operations. Further, with minimal training, the average Marine can utilize automated calls for fire and requests for air support that once required trained artillery officers and/or aviators to be embedded with the platoon.

7. Logistics

Cost (71 vs. 44 units)

Weight (see cost above)

Batteries (see cost above)

The ancillary benefit of adopting an IP-based solution will be that of reducing the load that the warfighter must bear when conducting combat operations. A single radio set, vice the multitude carried currently, will be a welcome relief.

G. CAPABILITY SETS

As mentioned previously, having permissions based on need is a fundamental ability that will reduce the burden on what precious amount of bandwidth the DO platoon will carry into battle. It is a foregone conclusion that the

chain of command carries with it specific authority that not everyone within the confines of a military organizational unit will or should have. The burden of command is written in stone.

However, the need for information does not carry rank and any communications system adopted by the DoD should bear this in mind; IP-based systems are not limited to this structure and the system envisioned by the authors has no such limitation placed upon it. The Capability Sets listed below are merely a reflection of the chain of command for authority's sake as well as the necessities of bandwidth limitations.

Capability Set 1 (CS1)

o (Basic) Routing, GPS (with pre-loaded maps for AOR), Capability to promote subordinate CS to same level (but not higher), VOIP, Limited Imagery, capability to sense other mesh enabled devices.

Capability Set 2 (CS2)

o CS1 + Limited video, improved imagery (higher resolution), file push (can transmit files to CS1. 9-line, Call for fire, Multicast.

Capability Set 3 (CS3)

o CS2 + Improved resolution video, Broadcast and Multicast.

These permissions are introduced as a starting point, the users should and will be the ultimate arbiter of what is needed for what mission and the author's believe that an

Open Architecture approach to designing these permissions is the best approach to finding the right solution for the needs of the Marine Corps and the DoD as an entire organization.

In unison with the Capability Sets, the authors envision a component solution as well. With the ability of every device to act as a router and bridging device, the network is strengthened by the ability of every Marine/node to transmit when needed. This gives the network the needed flexibility and robustness that a combat situation dictates. This solution is being explored by INTER-4, a subsidiary of the Sierra Nevada Corporation.

H. SCENARIO REVISITED

In order to demonstrate the benefits that the Marine Corps would gain by replacing the legacy communication suite with an updated IP-based communication suite, let us look again at the generic model of a DO platoon that was viewed during Chapter II. Instead of the platoon conducting combat operations with legacy communication equipment, let's view the same operations after the DO platoon are provided with an upgraded IP-based communication suite. The authors will demonstrate the "what if" condition based upon future constructs and communications protocols, illustrating the solutions provided by IP-based communications when operating in a distributed environment linked to other networks.

Based on proven technologies and research conducted at the Naval Postgraduate School, as well as commercial endeavors, the authors have constructed an improved DO

platoon enabled to conduct operations unambiguously, able to feed data to adjacent and higher units, keep constant location updates, and provide raw video to decision makers at all levels.

0330 14 October, after pre-combat checks, a platoon-sized unit departs and travels west out of Al Haqlaniyah in the Anbar province of Iraq enroute to checkpoint Buick, 60 miles away. Because the DO platoon will be utilizing an integrated PLI/GPS system, the platoon leadership and higher headquarters will be able to track the movement of the unit via a common operating picture (COP) at the tactical level which easily propagates the same vision up to varied higher headquarters (company, battalion, or higher as needed). The platoon will also be able to track the location of each element (down to the individual Marine, if required) as they travel toward checkpoint Buick on the COP. The PC, controlling Team A, will also be able to effectively maintain command and control of both Team A & B as well as his particular maneuver element as they move toward their operation base. If the PC wishes to split his forces, Team B can be tasked to travel along an alternative route while Team A continues on a pre-described route.

Once at the operating base, their mission remains to conduct patrols along the border to prevent the movement of insurgents into Al Anbar from the Syrian frontier. Communications between the deployed platoon and both the company headquarters and MEU Headquarters will be maintained continuously.

0630 14 October, once the DO platoon occupies an abandoned building well outside Khutaylah, the platoon

easily improve its communications links with the company headquarters and MEU Headquarters through its self-healing, self-forming, adaptive MANET network topology. Utilizing a system similar to those discussed in Chapter IV, a Tacticomp 5s will be with PC & PS, while Tacticomp 1.5 will be with each individual Marine. The use of an Omni-directional Micro-mesh router and airborne routing equipment (UAV, balloons, dedicated or chance aircraft in zone) will allow long range communication from anywhere within the platoon. A dedicated radioman will still be utilized, but each Marine in the platoon can serve as a router and a radioman if needed. With this nodal topology, and COP, the PLI for the entire dispersed platoon can be easily automatically passed to all units without SITREPs. The platoon's ability to maintain continuous PLI will assist enormously in command and control and reporting.

0700 14 October, since the DO platoon and all adjacent units are all using IP-based communications, they each have pre-established subnet ID's that are assigned to each piece of communication equipment and for the most part "never change." Therefore, the DO platoon that arrived in zone will not have a frequency set conflicts with adjacent units. Quite the opposite will take place: the DO platoon will be clearly identified within the zone and communication will likely approve as the adjacent units assist in the routing and passing of data. The radio checks are continuous and clear as a result of VOIP technology that eliminates static entirely. Furthermore, each Marine/node, including adjacent units, actually

improves overall communication range. This allows affective communication from the individual Marine to any available node via one IP-based radio (i.e. Tacticomp 5 or 1.5).

On order from the PC, Team B under the control of the PS and consisting of two squads, would move to an overwatch position where they will operate autonomously. As a result of their movement east of the town of Khutaylah, the platoon's communication would likely improve as nodes become more and more dispersed along the platoons frontage. The remaining two squads, Team A, will stay closer to the operating base under the control of the PC. These four squads, and approximately 42 nodes, would form a large MANET that would continuously update headquarters to their position as well as potentially linking up with border units or adjacent units using similar IP-based communication networks. As a result, a topology of nodes along the border would allow for deconfliction of direct fires as well as coordination.

Both Team A & B would remain well outside of supporting fires, but because of the teams ability to communicate over greater distances, support from adjacent units who maintain indirect fires, or the ability for a troop in contact to reach any aircraft in zone, would strengthen the unit without dedicated fires. Each member is trained in call for fire and terminal control for close air support (CAS), and as a result of inter-operable, each Marine can coordinate such fires as needed.

Because each additional unit within the battlespace (i.e., Air Force fixed wing, Naval fixed wing or Army rotary wing or indirect fires) are equipped and utilizing

the same IP-based radio communications equipment, the DO platoon is never off line. Additionally, the majority of the IP-based equipment does not require extensive vehicular assets. A small portable IP-based radio like the Tacticomp 1.5 contains a radio, GPS, and PLI. It provides a simple light weight device for use during foot-mobile patrols. The complement of radios and their primary role for each DO platoon is listed in Table 3.

	Nomenclature	Waveform	Range	Role
	Tacticomp 6	IP-based	Nodal dependent (5+ miles)	PC
	Tacticomp 5	IP-based	Nodal dependent (5+ miles)	PS
	Tacticomp 1.5	IP-based	Nodal dependent (1-3 miles)	PC down
	Omni-directional Micromesh Router	IP-based	Nodal dependent (12+ miles)	A & B Command elements Each squad

Table 3. Communications Equipment and Capabilities[66]

The complete Table of Equipment (T/E) would be:

1.5: 44 (Officer: 1, Corpsman: 1, Enlisted: 42)

5: 1 (1 for Team B Command group)

6: 1 (1 for Team B Command group)

MMR: 6 (1 per squad and 1 per command group)

[66] SNC Corp., ***INTER-4 Tacticomp Products***, <http://www.sncorp.com/prod/c4n/int4/default.shtml> 2006, (last accessed Aug 30, 2007).

In this example, the use of SNC Corporations Tacticomp products as an exemplar will demonstrate only one option. There are numerous other vendors, but the authors decided to use one currently fielded communication suite to demonstrate the potential. The overall platoon complement of radios is a combined total of 46 per platoon.

2030 15 October, after 36 hours in zone, the two DO platoon's teams are dispersed and positioned along a extended frontage in order to observe as much battlespace as possible. At this time a Team B observes two groups of armed men in pickup trucks moving towards the village of Khutaylah from the west. Using an enhanced video feed that is built into the IP-based system, the PS directs a member of his Team to send a live night-time feed via multi-cast video to all platoon members in order to ensure all platoon members identify the potential threat. Via chat and utilizing a pre-formatted SITREP, the team reports their position has not been compromised and that they will continue to observe from their observation position.

2040 15 October, Based on the complement of weapons seen by the PC and as a result of the Team B's SITREP, the PC initiates a call for CAS via a mono-cast transmission between himself and Team B. During the CAS request, the PC identifies the PS subnet ID and advises the DASC of that the PS will control fires and reconfirms his subnet ID. At this point, a Section of Air Force F-16s is returning from an aborted mission. The F-16s are cleared through DASC to work directly for Team B PS and immediately come up via VOIP with the PS. At that time, the PS transmits the current video feed of the target and the laser designation

grid for the target. The section leader re-confirms all blue force locations and the friendly lead trace which he automatically received and propagated on his in-flight computer.

2055 15 October, as final preparations for the strike are completed, the two teams of insurgents begin to move out of their location. The first truck speeds west towards Khutaylah and the platoon's operating base, while the second is delayed due to vehicular issues. While the insurgents are working to repair the vehicle, the first BLU-126/B hits the building and destroys the structure, damaging the vehicle and the scattering the remaining insurgents.

2100 15 October, the section of F-16s reports that due to their previous mission, they have no more time on station and immediately depart the sector. Since Team B has maintained observation of the insurgents through the use of NVG, the final task of destroying the target is tasked to the Marines of Team B, while the task of destroying the remaining vehicle falls to the PC and Team A. The PS finalizes the coordination required to execute an assault on the remaining insurgents by sketching the scheme of maneuver on an overlay that is built into the PLI/GPS system. The PS then sends this overlay via file transfer to the PC via mono-cast broadcast. The PC immediately views the intended action and sends his approval. The PS receives the approval and multicast the overlay to his two squads. In a follow on file transfer the PC transmits to the PS, via mono-cast, the overlay which depicts the location for Team A's forthcoming ambush.

The PS verifies the receipt of his mission and acknowledges that PC and Team A will engage the escaping truck.

2215 15 October, the PS, utilizing his laser designator, marks the escaping vehicle and transmits the grid via chat to PC to assist in the overall prosecution of the target. Based on traffic sent via video feed to ID target, and chat to further identify target location, the PC initializes a hasty ambush. Utilizing multi-cast, an overlay for the forthcoming ambush is sent via file transmission that indicates enemy location, primary and alternate ambush sites, fields of fire for squads, and commander's intent. PC further directs both squads via multi-cast VOIP. 1st squad is to set up on the far side of the road and is to engage when the truck is in sight. 2nd squad is to stay on the near side and support 1st squad when the insurgents dismount.

2225 15 October, concurrent with Team A's planning; the PS and Team B begin their assault on the remaining insurgents who have taken up a defensive position in a structure adjacent to the destroyed building. Team B, utilizing its 3rd squad as a support by fire position and its 4th squad as an assault unit, begins its attack on the insurgents held up in the smaller structure. This was all drawn into an overlay and transmitted to all members of Team B via multi-cast. Via VOIP, the PS detailed that he would travel with the assault. Since each Marine carries a IP-based radio, each Marine's lead is traced will be continuously transmitted to all Team B members and therefore visible to support by fire squad. Additionally, target reference point, fire control measures are transmitted on an overlay via multi-cast from PS to Team B

members. Enhanced with these capabilities, Team B's assault was successful. During the assault, the target reference points and phase lines depicted on the squad COP ensure all members of the team are clearly visible and assist in the team's ability to deconflict action on the ground. During the assault, the remaining insurgents were killed and an enormous amount of intelligence was collected from the destroyed building, truck, and from the neutralized insurgents. This data was collected immediately via video and transmitted to headquarters for further exploitation. Additionally, prior to the assault, the platoon guide transmitted the Battle Damage Assessment from the CAS.

Concurrent with Team B actions, Team A engages the vehicles and the insurgents which were heading toward Khutaylah. The insurgents are engaged and the vehicles come to a halt just west of the ambush site, immediately firing in the direction of 1st squad. Communication traffic over the IP-based radio is kept to a minimum as a result of the availability of data being transmitted over the COP. Additionally, Marines rely upon training to work through the fog of war, but even with NVG's, it is difficult to discern good guys from bad. A team from 2nd squad identifies an opportunity to establish a support by fire position and has no time to transmit his intention. Instead, seeing an opportunity to seize the initiative and meet his commanders intent, he dashes his team across the road to support 1st squad. 1st squad is able to identify this movement via PLI of the adjacent unit on the COP. As a result of the 2nd squads exploitation the conflict between the insurgents and Team A ends immediately.

0035 16 October, after a few hours of site exploitation and intelligence gathering, the PC transmits to the entire platoon via VOIP broadcast. The PC conducts a quick read back of all data consolidation after the CAS strike, assault, and ambush and transmits this data and any additional video and imagery, as well as after action data in report formats and in historic overlays.

0200 16 October, after headquarters has confirmed receipt of after-action, the PC orders the PS and Team B to their new observation positions via mono-cast file transfer. As the PS moves his teams to their positions, the PC follows send his final patrol order which indicates that continued patrolling is required. Team A and the PC remained tied into the structure of the former border fort, while Team B pushed back out to an overwatch position well out of sight of the town and away from the previous compromised observation site. Once in their observation position, the COP self-generates and the follow-on reports arrive via chat throughout the early morning.

2200 17 October, Team A is nearing completion of their patrol when it is tasked to conduct a physical link-up with a DO platoon who would be patrolling to the northeast and adjacent for the forthcoming days. Mission orders released prior to crossing the Line of Departure (LOD) indicate the subnet ID of the second platoon and thanks to the self-forming network, communication with second platoon can be made well before the platoon departs its current location over 35 miles east of first platoon’s location.

Scenario Analysis: The scenario given above depicts the benefits that a properly equipped DO platoon operating within a network-centric battlespace can achieve during combat operations. With fewer radio sets, Marines are able to easily expand communications across a much larger battlespace and interact directly with more supporting and adjacent units. Further, this provides direct access to the GIG through reachback and develops the COP at the Tactical, Operational, and Strategic levels of command. Not having to continually switch radio sets to communicate within the platoon simplifies information transfer and reduces the fog of war, by not having to bring them in the first place, reduces the burden the Marine has to carry. Finally, the ability to transmit data (video, imagery, biometrics, PLI and files needed to update the COP) further reduces uncertainty, assists in the dissemination of decision-making, and helps in the advancement of small unit leaders vigorously pursuing the commander's intent in accordance with the warfighter mentality.

Until the Marine Corps truly transitions from legacy radio equipment to IP-based equipment, they will continue to fight in the fog.

I. CONCLUSIONS

This chapter provided numerous insights into new technologies that provide remarkable benefits to the organization as a whole and the warfighter specifically; among these are increased operational picture at all levels, versatile communications packages, more capable communications equipment, clear communications, reduction

in weight of overall number of devices taken into combat, and reduced fog of war with a COP through connectivity to the GIG.

The authors posit that the Marine Corps must take decisive action to bring their communications architectures into the 21st century and align their vision with that of the Joint Chiefs of Staff Joint Vision 2020. The technologies described earlier in this chapter are just a sampling of what is available currently and how civilian corporations are working to develop suites of products to answer the call by the DoD. Unfortunately, the Marine Corps has no plan to move to the nexus.

V. CONCLUSIONS

[Distributed Operations] is not about distance between units; it is about superbly trained and equipped small unit leaders and tactical units that give our operational-even strategic-commanders an additional weapon in the brutal, yet increasing sophisticated, Global war on Terrorism.

Vincent J. Goulding[67]

A. WHY FIX WHAT IS SOON TO BE BROKEN?

Organizations, specifically the DoD, have consistently been resistant to change for a number of reasons. The Marine Corps, though, has led the way in adapting to rapidly changing environments throughout the Marine Corps' history. The Marine Corps have innovated amphibious landings, close air support, vertical envelopment, Combined Action Platoons, and encouraged command initiative to be taken at the lowest level possible. This needs to happen for communications, as well. As demonstrated in the body of this thesis, the current telecommunications architecture is insufficient to handle the needs of the newest Marine Corps innovation, the Distributed Operations platoon.

Despite advancing such progressive innovations as the DO concept (currently fielding between two and four infantry battalions[68]) the Marine Corps persists in equipping these Marines with a complement of legacy equipment similar to that discussed in Chapter II and seen

[67] Colonel Vincent Goulding, Jr. USMC (ret), Director, MCWL, ***Distributed Operations***, Feb 10, 2006, briefing.

[68] Mark Richter (Program Manager MERS, MARCORSYSCOM), interviewed by Chris C. Curran, request for information on the MERS Program, July 22, 2007.

in Table 1. The authors understand the desires of the Marine Corps to urgently equip the infantryman with the most advanced communications equipment available, but the authors feel that continuing to field legacy equipment serves only as a stop gap method and is not a true solution, as it only adds to the logistical burden of the individual Marine and inhibits the needed evolution to Network-Centricity. Until the Corps completely severs itself from legacy communication equipment and adopts an IP-based system it will continue to fall short of effectively transitioning the nations forces to a Network-Centric vision. As a result, the Corps will continue to lag behind each of its sister services and national allies. The authors see this as a critical flaw in the vision of the Marine Corps and one that could potentially be fatal as communications technologies proceed to outpace the Corps' ability to modify legacy systems in order to stay connected to the network.

Today, the USMC continues to press forward with the concept of DO through laboratories and schools such as the Marine Corps Warfighting Laboratory (MCWL) and the Naval Postgraduate School (NPS). MCWL continues to push the envelope of DO with at least a half dozen different Limited Objective Exercises (LOE) in the forthcoming two[69] years, while NPS continues to work hand-in-hand with sister services conducting experiments and research during quarterly Tactical Network Topology (TNT) field experiments. The focus of these experiments is on equipping small units with innovative communication systems

[69] Colonel Vincent J. Goulding Jr., "RE: Visit to MCCDC on 13 SEP?," Jul 24, 2007, personal email (Aug 28, 2007).

that provide the C2 backbone needed to dominate in the aforementioned infestation or swarming warfare arena. The DO unit will remain connected through technology, lethal through integrated fires, and capable through increased training at all levels. This transition from a chain network to an all channel network facilitates and forces a transition from what James D. Thompson describes as a "pooled, sequential interdependency" to a "pooled, reciprocal interdependency."[70] The DO concept at the very least equals any cutting edge adaptation in the history of the Marine Corps and once coupled with dynamic technological advances is the right fix at the right time.

B. CONCLUSION

As the authors described in the benefits section of Chapter IV, the author's research has shown there has been a tremendous amount of effort placed on bridging the gap between current legacy radio technology and imminent transition to IP-based technologies (Tsirlis and Craig) such as those that are being evaluated and fielded by the Stryker Brigades and Ranger Battalions. The ability to pass data and information between these two radically different forms of communication will be of enormous value and is critical for the nodal IP-based system to function in the NCW of tomorrow.

To properly adapt the USMC's doctrinal communication networks to the advancing threats and to meet forthcoming

[70] James D. Thompson, ***Organizations in Action: Social Science Bases of Administrative Theory,*** (New York: McGraw-Hill, 1967), pages 54-55, references in Roberto Weber, ***Organizational coordination: A game-theoretic view,*** (Pittsburgh: Carnegie Mellon University, School of Social and Decision Sciences, 2005), pp.14-29.

technological advances the USMC must take the lead from its other services in the rapid deployment of future combat communication systems. The authors feel that if the Marine Corps is to live up to its expeditionary nature, the Marine Corps must be the first ashore with a communication architecture that is interoperable with all services, lest they dictated to as to which flavor of communication is available at the time. This can be done no better than with the use of IP-based communication systems as described throughout this thesis.

The Marine Corps is headed toward a precipice but can easily avert disaster by developing and adopting a communications architecture that is removed from legacy, push-to-talk radios. The Marine Corps Warfighting Lab (MCWL) have indicated an interest in IP-based systems, but to-date, no efforts have been enacted to equip Marine DO units with this technology. The Marine Corps has always been the leader in innovating adaptive warfighting techniques and been on the cutting edge of new platforms such as the AV-8B, MV-22, and the EFV, why do they fail to recognize the new wave of communications technologies?

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